Instruction Manual

MODEL 3216 ROOF MOISTURE GAUGE

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I. INTRODUCTION AND SPECIFICATIONS

I-A. INTRODUCTION

This instrument is specifically designed for performing roof moisture surveys. A radioactive isotope consisting of americium-241 with a beryllium target is utilized.

The measurement method relies on the thermalization of fast neutrons by the hydrogen atoms in water. Since other hydrogen bearing materials also thermalize neutrons, a measurement survey is necessary to establish a relative base level before an analysis can be performed.

The 3216 is a portable instrument with a periodic counter to measure the rate of thermalization of neutrons.

Portions of this manual are used in training courses offered by the manufacturer to help the purchaser to get a Radioactive Materials License from either the U.S. Nuclear Regulatory Commission or an Agreement State. The manual may also be used for additional operator training, and the manufacturer encourages owners to require the study of the manual before allowing any prospective operator to use the instrument.

There is no radiation hazard for the operator(s) when normal recommended use of procedures is followed; a potential hazard does exist if the instrument is used improperly. All operators should read the sections covering radiological safety. If these procedures are not completely understood, users should seek assistance from the factory or others designated within the user organization. Additonal nuclear safety information is available by attending a TROXLER NUCLEAR GAUGE TRAINING COURSE.

Since changes are continually made in state and federal regulations, the user must keep up-to-date with the appropriate regulations. The final responsibility for compliance with the regulations falls upon the owner. He may wish to purchase and subscribe to Title 10 and Title 49 of the Code of Federal Regulations, as well as the applicable State Regulations which apply to his license.

* * NOTICE * *

Due to the large percentage of international users of these gauges and the growing acceptance of the metric system in professional environments, the SI (Systeme International) units are used as the standard in this manual. The U.S. customary units are shown in parenthesis for convenience.

The SI units for radiation measurements are not in general use, so the older units are used throughout the manual and conversions are quoted here as a reference.

1 Ci = 3.7×10^{10} Bq (37 gigabecquerels)

1 rem = 3.876×10^{3} C/kg (3.876 kilocoulomb/kilogram)

I-B. DEFINITION OF TERMS

PRECISION defines the statistical limits of the instrument based on changing rates of radioactive decay. The value stated is the standard deviation limit. Precision may be determined by statistical analysis of repetitive measurements (20 or more) or may be computed by the square root of the actual counts accumulated divided by the slope (first differential) of the calibration equation. The value defines the repeatability of the measurement or the minimum change in moisture which is detectable by the instrument. See Figure 9-2 for a graphic illustration of precision.

DEPTH OF MEASUREMENT defines the depth through which 95% of the counted thermal neutrons pass before reaching the detectors. The depth is dependent on the absolute hydrogen content or apparent water.

I-C. SPECIFICATIONS

I-C-1. MEASUREMENT SPECIFICATIONS (SI UNITS)

	7.5 SEC	15 SEC	60 SEC	
Precision at 200 kg/m^3	11.9	8.4	4.2	$\pm$kg/m^3
Depth of Measurement at 200 kg/m^3	<--------225-------->			mm
Useful Measurement Range	<------0-1000------->			kg/m^3

MEASUREMENT SPECIFICATIONS (U.S. CUSTOMARY UNITS)

Precision at 12.5 PCF	0.74	0.52	0.26	$\pm$PCF
Depth of Measurement at 12.5 PCF	<--------8.9-------->			inches
Useful Measurement Range	<--------0-62.4----->			PCF

I-C-2. MECHANICAL SPECIFICATIONS

Gauge Materials	Stainless Steel Base, Anodized Aluminum Handle, ABS Plastic Top Cover	
Vibration Test	2.5 mm (0.1 inches) at 12.5 Hz	
Operating Temperature	-10 to 70°C	(14 to 158°F)
Storage Temperature	-55 to 85°C	(-67 to 185°F)
Surface Contact Dimensions	190 x 229 mm	(7.5 x 9.0 inches)
Height with Collapsed Handle	495 mm	(19.5 inches)
Height with Extended Handle	770 mm	(30.3 inches)
Weight	4.1 kg	(9.0 pounds)
Shipping Weight	12 kg	(26.5 pounds)
Shipping Case	670 x 406 x 330 mm	(26.5 x 16 x 13 inches)

I-C-3. CALIBRATION SPECIFICATIONS

Number of Standards	2
Accuracy of Standards	±4.0%

I-C-4. RADIOLOGICAL SPECIFICATIONS

Neutron Source	1.48 ± 10% GBq (40 ± 10% mCi) 70,000 n/sec yield, TEL A-102451
Source Form	Stainless steel, encapsulated
Source Classification per ANSI N542-1977	ANSI-C54444
Shielding	Lead and Polyethylene
Maximum Surface Dose Rates	See Radiation Profile on page 10-6
Shipping Case	DOT 7A, Type A, Yellow II Label, 0.1 TI
Special Form Approval	Am-241, SPECIAL FORM Certificate GB:SFC 7
Gauge Classification per ANSI N538-1979	ANSI-54-685-685-R2

I-C-5. ELECTRICAL SPECIFICATIONS

Time Accuracy and Stability	± 0.005% ± 0.0002%/°C
Power Supply Stability	± 0.01%/°C
Battery Capacity	14 W-hr
Charge Source	115/230 V, 50-60 Hz or 12-15 VDC
Battery Recharge Time	
AC Charger	14 hr
DC Charger	3 hr
LCD 4 digits	
Largest Number Displayable	9999
Count Registers	1
Power Consumption	0.08 W
Power Consumption after Automatic Battery Cutoff	0.001 W

Battery packs are fully protected against overcharge and overdischarge. Low Battery alarm is indicated on the display several hours prior to automatic cutoff.

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II. OPERATING INSTRUCTIONS

II-A. GETTING ACQUAINTED

The gauge is a portable instrument containing electronic modules, detector tubes, rechargeable battery packs, and a radioactive source. The handle can be adjusted to a comfortable height for the user and tilted to permit the gauge to be easily slid under air handling units mounted above the roof.

The 3216 gauge provides a fast and economical method for performing the data collection task necessary for roof moisture surveys. Before you attempt to use your gauge, spend a few minutes learning its features and controls. This section will act as a "Dry Run" to acquaint you with the instrument.

Remove the gauge and accessories from the shipping case and place the gauge on the floor in front of you. The tilting handle should be fixed in the upright position by tightening the knob at the base of the handle.

Two battery chargers are supplied with the gauge. Refer to Section V-A for use of these units.

II-B. CONTROL FUNCTIONS AND OPERATIONS

Refer to the front panel of the instrument. The POWER/TIME switch controls power to the gauge and also selects the duration of the accumulation (counting) period. Turn the POWER/TIME switch to 7.5 SEC.

The ERR symbol will appear in the upper left corner of display indicating the gauge is accumulating data. Since the gauge "powers-up" in the counting condition, this initial count is invalid and must be disregarded.

If the batteries are in need of a recharge, the BAT symbol will appear below the ERR symbol.

There are two START buttons on the gauge. One is located on the front panel, and a remote START is located on the gauge handle. These switches are connected in parallel, and either can be used.

Press either START switch; the ERR notation will appear in the display. At the end of the accumulation period, the ERR symbol will disappear and the gauge will emit a brief "beep". If this were an actual test, the number displayed should be recorded and another count could be started.

The RATEMETER, located on the top of the cover, is useful for fast visual indication of count rate. You can see the effect of this meter by raising and lowering the gauge over a hydrogenous material (use the 3216 shipping case). This meter is not calibrated and therefore should only be used as a quick indication of count rates. The RATEMETER has a logarithmic response providing greater sensitivity at the low end of the scale.

The CHARGER connector is used with either of the battery chargers supplied with the unit. When the batteries are receiving a charge, the indicator adjacent to the connector will light.

II-C. TEST FUNCTIONS

There are two tests that can be performed if defective operation is suspected. The first and easiest test is to let the gauge count a hydrogenous material which produces a known count rate. A concrete floor covered with asbestos tile will produce a count of approximately 25. A count taken with the gauge placed on its shipping case will produce a count rate of approximately 10.

The second test involves removing the top cover and substituting a test signal of known rate in place of the moisture modules. See Section V-D and VI-B for disassembly instructions and switch location, respectively.

After the cover has been removed, slide the TEST/MEASURE switch to TEST. Placing the POWER/TIME switch on any of the time positions and pressing the START button should result in a count of 38 $\pm$3.

If the scaler accumulates the correct count for the three time positions, you can be reasonably confident the scaler is functioning correctly.

III. FIELD MEASUREMENTS

While the 3216 can be used for accumulating data on any hydrogenous material, it is designed specifically for performing roof moisture surveys. For this reason, the section will be limited to roof moisture considerations.

The procedure provides a nondestructive means of tracing wet sections of a built-up roof to determine damaged areas before or after a leak has penetrated the roof structure. The survey can greatly reduce maintenance costs due to the ability to define areas needing repairs before total replacement becomes necessary.

The procedure requires a statistical analysis of data collected during a roof survey. The analysis will indicate which sections of the roof have an elevated count rate indicative of water penetration. Only relative moisture levels can be determined unless the gauge is calibrated for the particular roof. The zero moisture count rate will vary widely due to the quantity of organic material, asphalt thickness, etc. The slope of the calibration will vary due to changes in thickness. If absolute quantities of moisture content are required, several core samples will have to be cut from the roof material and used for calibration purposes.

Roof moisture surveys can be divided into two main functions: 1) data collection, and 2) data reduction and analysis. The data collection process is described in Section III-A. Data reduction and analysis can be done either manually or with computer aided graphics. The manual procedure is described in Section III-B, and the computer aided procedure is described in Section III-C.

III-A. DATA COLLECTION

The result of the data collection process is a gridded drawing of the roof with moisture measurements recorded at the grid intersections. See Figure 3-2 for an example. With this goal in mind, the suggested method is shown below.

III-A-1. SELECT GRID SIZE

The grid size determines the total number of data points, data collection time, and resolution. There is no hard and fast rule for determining the optimum size. The table below illustrates the effects of various grid sizes.

100' x 200' ROOF

Grid Size	Roof Plan Size	Number of Data Points	Data Collection Time in Hours (*) 7.5 SEC Mode	15 SEC Mode
3' x 3'	33 x 66	2178	7.6	12.1
5' x 5'	20 x 40	800	2.8	4.4
6' x 6'	16 x 33	528	1.8	2.9
10' x 10'	10 x 20	200	0.7	1.1

(*) assumes 5 sec between measurements.

III-A-2. LAYOUT GRID ON ROOF

The grid pattern (at the selected size) must be laid out on the roof. Paint, strings, marked ropes, or other methods can be used to define the grid intersections on the roof.

One popular method is to use two marked ropes, placed parallel on opposite sides of the roof. A third marked rope is stretched between the two parallel ropes. With spray paint can spot the roof at each marking on the rope. The "marking stick" listed in the Accessories Parts List (Section VII-B) is especially useful for this purpose.

III-A-3. DRAWING OF ROOF PLAN

Make a scaled drawing of the roof's top view. Note on this drawing all roof structures (drains, heating and air conditioning units, ventilation shafts, etc.). If there are no roof structures or other details that indicate building orientation, then note the north orientation on the drawing.

Any roof structures the user wishes included on a plot must also by shown on the roof plan.

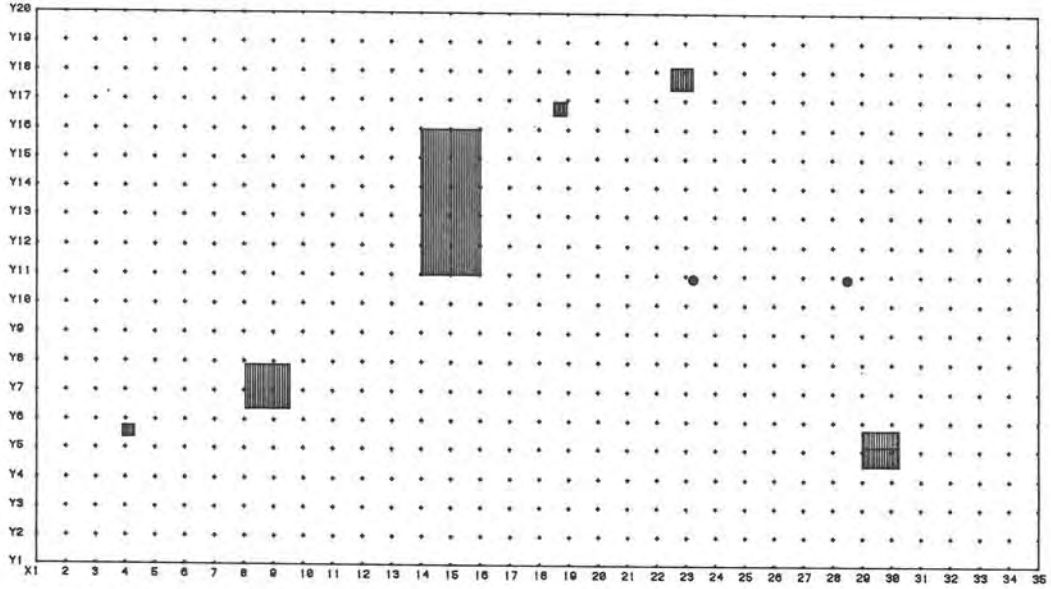
III-A-4. COLLECT MEASUREMENT DATA

Set the POWER/TIME switch to the desired accumulation time period. Use the gauge to make a measurement count at each grid intersection. Record this count at the correct position.

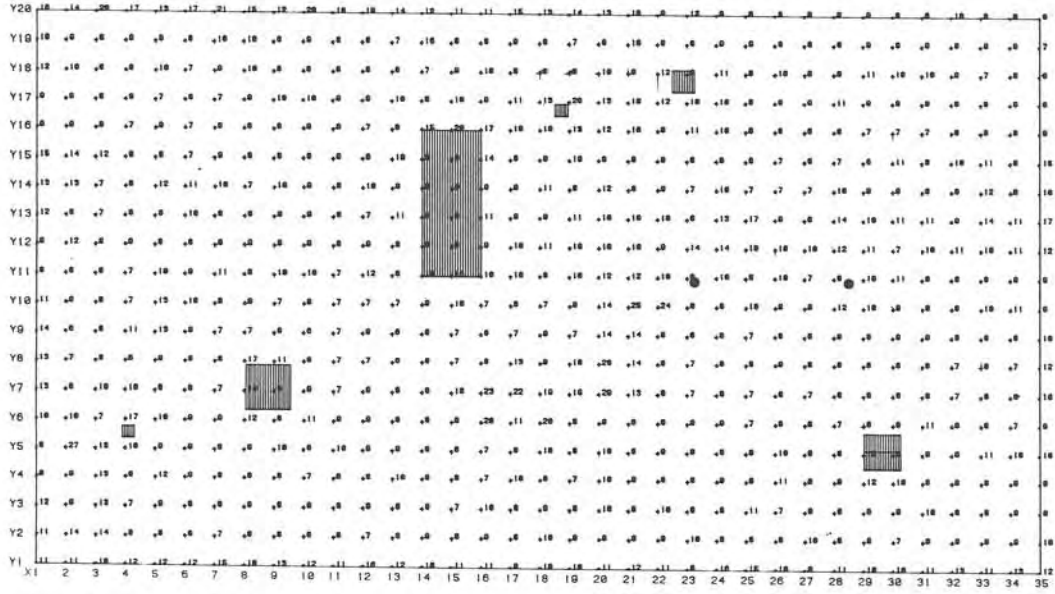
III-A-5. CUT CORE SAMPLES

Nuclear gauges register relative hydrogen levels. If absolute moisture levels are needed, one must correlate count rates and actual moisture levels. Correlation is normally done via core samples.

The core samples should be chosen to include the widest range of count rates possible. The roof plan count rate data will be useful in choosing where to cut core samples. If a limited number of core samples are to be cut, then they should be made at sites (determined from the count data) that indicate a transition from dry to wet.



Gridded Roof Plan
Figure 3-1



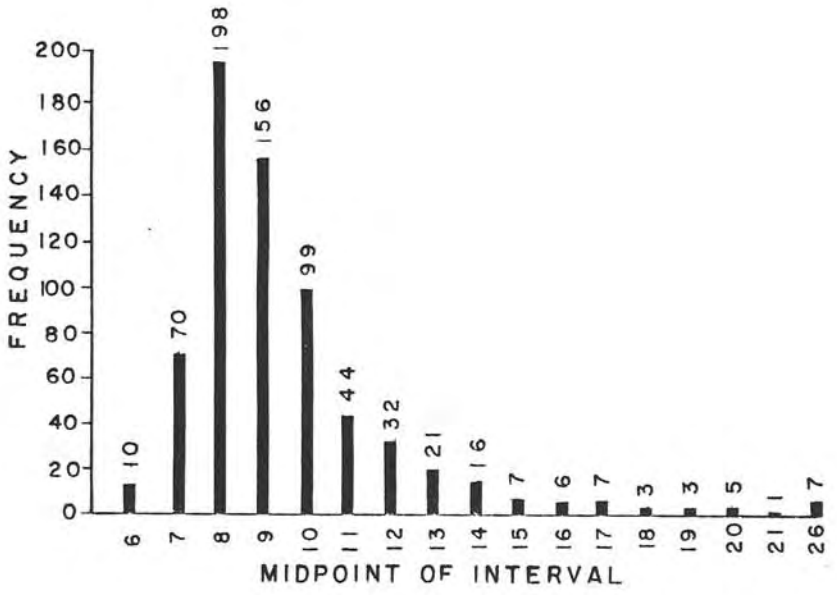
Roof Measurement Data
Figure 3-2

III-B. MANUAL ANALYSIS OF DATA

III-B-1. FREQUENCY HISTOGRAM

A frequency histogram is normally used to reduce the volume of data into a compact form. A histogram simply groups data points by defining intervals and combining all data points that fall within that interval. For example, if the midpoint of an interval is 15 and the width of the interval is 3, then any data point between 13.5 and 16.5 would be included in this interval. Odd integers (3, 5, 7, etc.) are normally used as interval sizes because they always have a whole number as the midpoint. The "frequency of occurrence" is simply the number of data points that fall within a given interval.

When dealing with large numbers, the interval size must be carefully defined in order to produce a meaningful histogram. The interval size should be large enough to ease the computational task which will occur later but small enough to easily distinguish the normal distribution produced by the dry sections of dry roof. Fortunately, the 3216 helps solve this problem. The amount of prescale designed into the counter circuits allows the user to treat each integer as a histogram interval. For the data shown in Figure 3-2, the histogram is produced in Figure 3-3. To keep the histogram within a manageable range, the top 1 to 2 percent of the counts are combined into one interval.

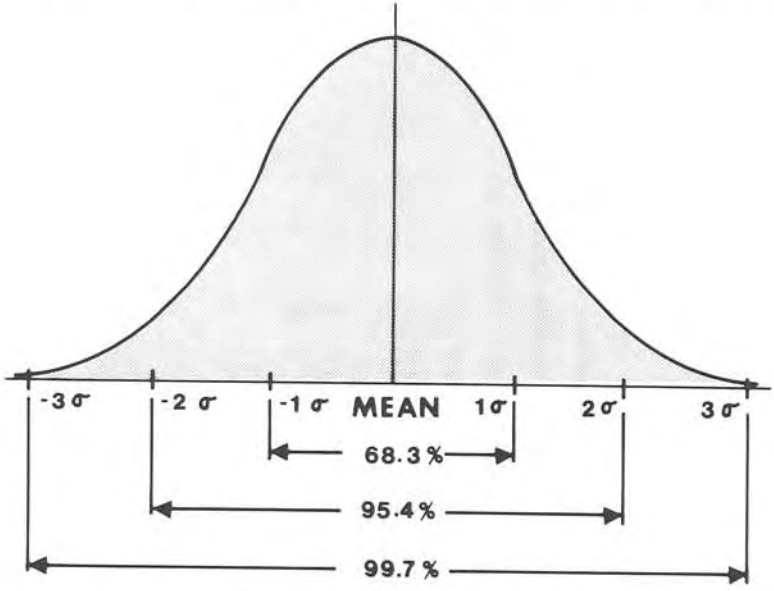


Histogram of Sample Data
Figure 3-3

III-B-2. STATISTICAL ANALYSIS OF DATA

A limited knowledge of statistics is necessary to be able to interpret the histogram produced in the previous step.

The histogram produced by using a nuclear gauge on a dry roof (or any other hydrogenous material) will form a bell shaped curve. This curve is called the "normal distribution" and looks like Figure 3-4.

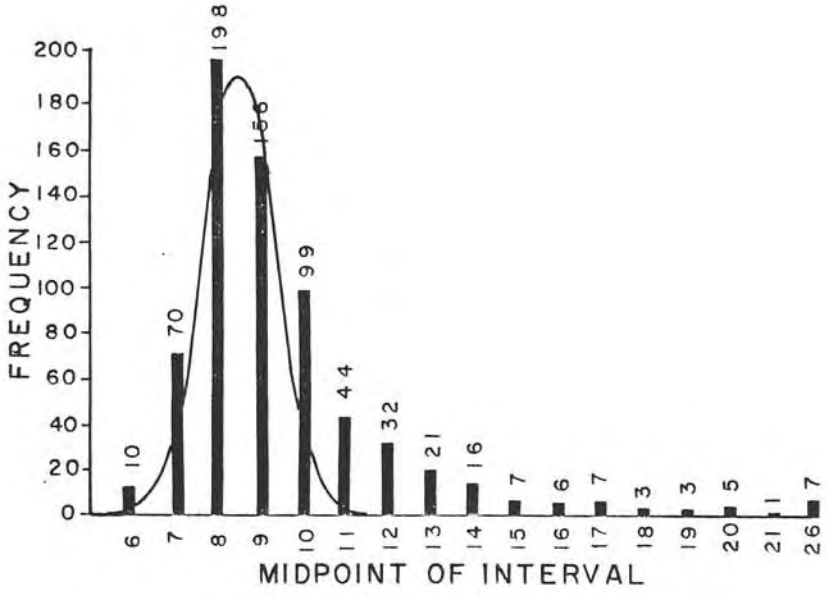


Normal Distribution with Confidence Limits
Figure 3-4

Certain conditions must be met to be able to produce a "statistically meaningful" curve. First, the material must be homogeneous. Second, enough data must be taken to allow the normal distribution to appear. By looking at the data in Figure 3-3, one sees that 20 measurement counts, taken at random sites, would not have produced a similar histogram. As a guideline, a minimum of 100 points is necessary to produce a usable histogram.

The "width" of the normal distribution is determined by the standard deviation. The equations for calculating this number are given later in this section. The importance of the standard deviation is that once the mean and the standard deviation are known, you can define the "end points" of the normal distribution, and, therefore, the count rate range for dry areas of the roof. 99.7% of the measurement counts for the dry areas of the roof can be expected to fall between the three σ limits.

Knowing that the dry areas of the roof will produce a normal distribution, this curve should be overlayed on the measurement data histogram. A graphic overlay for the sample data is shown in Figure 3-5.



Normal Distribution Overlaying Histogram
Figure 3-5

To verify the assumed endpoints for the overlay process, calculate the mean and standard deviation. The mean is simply the sum of the midpoint of the histogram interval multiplied by the frequency of occurrence and divided by total number of points. The equation for the mean is:

$$\bar{X} = \frac{\Sigma(Xi \times Fi)}{N} ,$$

where: X_i = the midpoint of histogram interval,
F_i = frequency of occurrence for a particular interval,
N = total number data points.

The equation for standard deviation for grouped data is:

$$s = \sqrt{\frac{\Sigma((X_i)^2 \times F_i) - \frac{(\Sigma(X_i \times F_i))^2}{N}}{N-1}}$$

This equation can be implemented very easily with a programmable calculator or a small computer. For reference, a sample program for this equation is included in Appendix AI. This program was written in the BASIC programming language.

If a programmable calculator is not available, the equation can be implemented as shown in Figure 3-6. A data table is produced and the intermediate calculations recorded. A summation of the columns yields the necessary data. For this solution, the equation is rewritten as:

$$s = \sqrt{\frac{\Sigma_b - \frac{(\Sigma_a)^2}{N}}{N-1}} \quad ,$$

where: $\Sigma_a = \Sigma(X_i \times F_i)$, $\Sigma_b = \Sigma((X_i)^2 \times F_i)$, and $N = \Sigma F_i$.

Once the summations are found, the equation is easy to solve.

The three standard deviation limits on each side of the mean should be calculated from:

Lower Limit = Mean - 3s , Upper Limit = Mean + 3s

X_i (Midpoint of Interval)	F_i (Frequency of Occurrence)	$X_i \times F_i$	$(X_i)^2 \times F_i$
6	10	60	360
7	70	490	3,430
8	198	1,584	12,672
9	156	1,404	12,636
10	99	990	9,900
11	44	484	5,324
	$N = \Sigma F_i = 577$	$\Sigma_a = 5,012$	$\Sigma_b = 44,322$

$$\bar{X} = \frac{\Sigma_a}{N} = \frac{5,012}{577} = 8.69$$

$$s = \sqrt{\frac{\Sigma_b - \frac{(\Sigma_a)^2}{N}}{N-1}} = \sqrt{\frac{44,322 - \frac{(5,012)^2}{577}}{576}} = \sqrt{1.365} = 1.17$$

Lower Limit = Mean - 3s
= 8.69 - 3(1.17)
= 5.18

Upper Limit = Mean + 3s
= 8.69 - 3(1.17)
= 12.2

Standard Deviation for Grouped Data
Figure 3-6

For the sample data, the assumed endpoints were 6 and 11. From Figure 3-6, the calculated endpoints were 5.18 and 12.2. This experimental result shows reasonably good agreement with theoretical expectations.

III-B-3. CORRELATING CORE SAMPLES AND MEASUREMENT DATA

As explained in Section II-A-5, the count rate data yields relative moisture levels. If absolute moisture levels are necessary, one will need to cut several core samples and use laboratory techniques to determine the actual moisture levels. The core samples should be chosen to include as wide a range of measurement counts as possible.

This procedure will only be valid for the particular roofing system on which the correlation was done. Also, the roofing system must be uniform (i.e., no patches or reroofed sections).

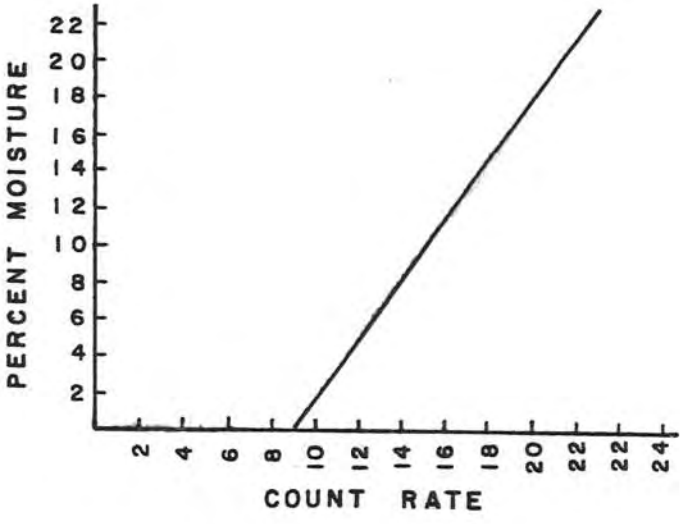
Once the actual moisture levels have been determined, a straight line graph can be drawn relating count rates to the actual moisture levels.

The measurement counts may be converted to a defined unit of measurement such as percent moisture. For our example, zero percent moisture may be defined as the mean of the dry area, or 9. A core sample cut from a site with a count of 8 or 9 should yield a zero percent moisture. If a core sample cut from the site with a count of 20 yields a moisture content of 18%, then the slope (rate of change) for the moisture graph would be [18/(20-9)]. By subtracting the count rate for the zero moisture offset (count rate - 9, for this example), the equation for percent moisture becomes:

$$\text{Percent Moisture} = (\text{count rate} - 9)\ \frac{18}{(20 - 9)}$$

$$= (\text{count rate} - 9) \times 1.64$$

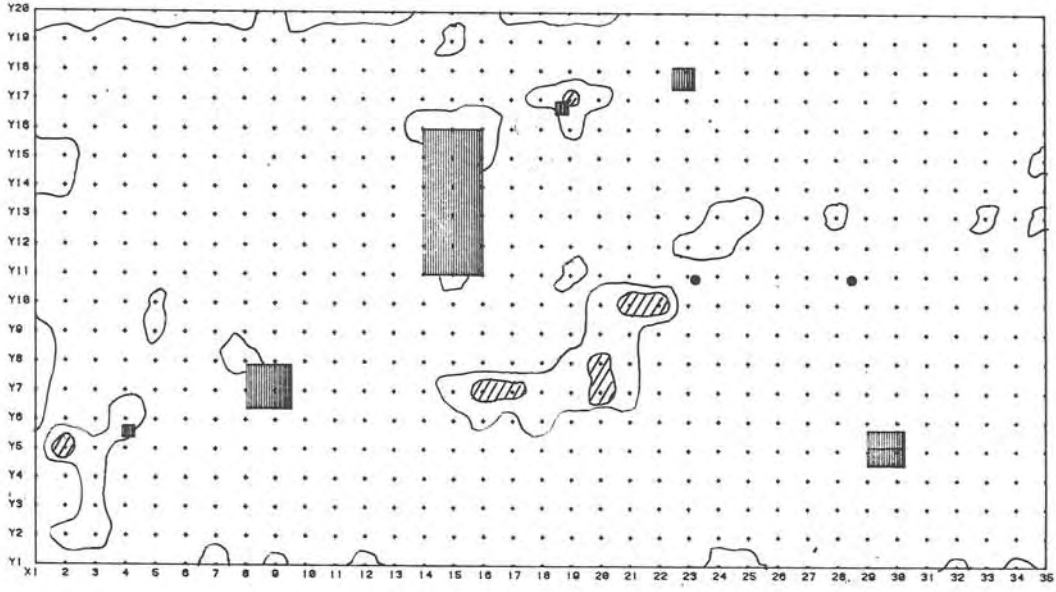
The graph for the sample data is shown in Figure 3-7.



Percent Moisture Correlation Graph
Figure 3-7

III-B-4. GRAPHIC PLOT

Now that the wet areas can be defined from the count rate data, a graph of the roof plan can be drawn to summarize the survey. Only the wet areas need be shown. Therefore, for the sample data, only counts above 12 need be considered. Three or four new intervals of relative "wetness" should be sufficient for a normal survey. Figure 3-8 shows a graph of the sample data.

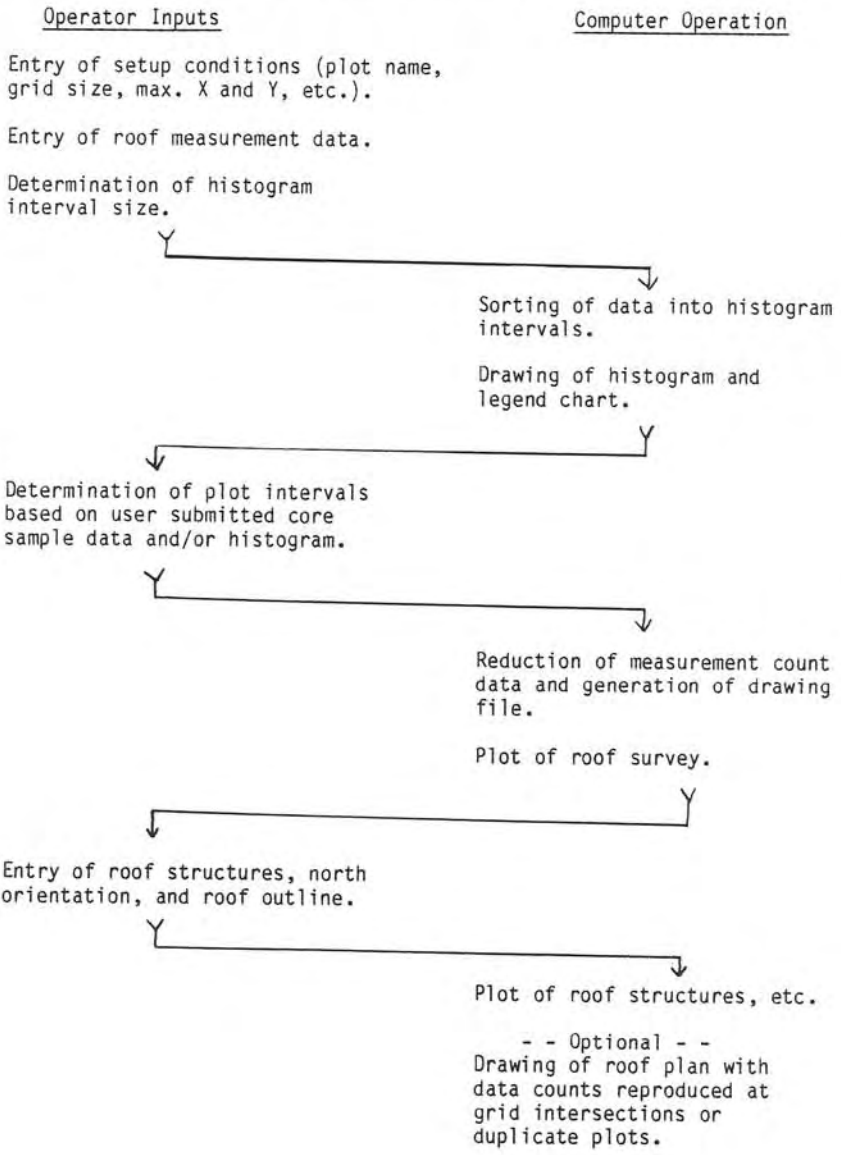


Graphic Interpretation of Roof Survey
Figure 3-8

III-C. COMPUTER AIDED ANALYSIS OF DATA

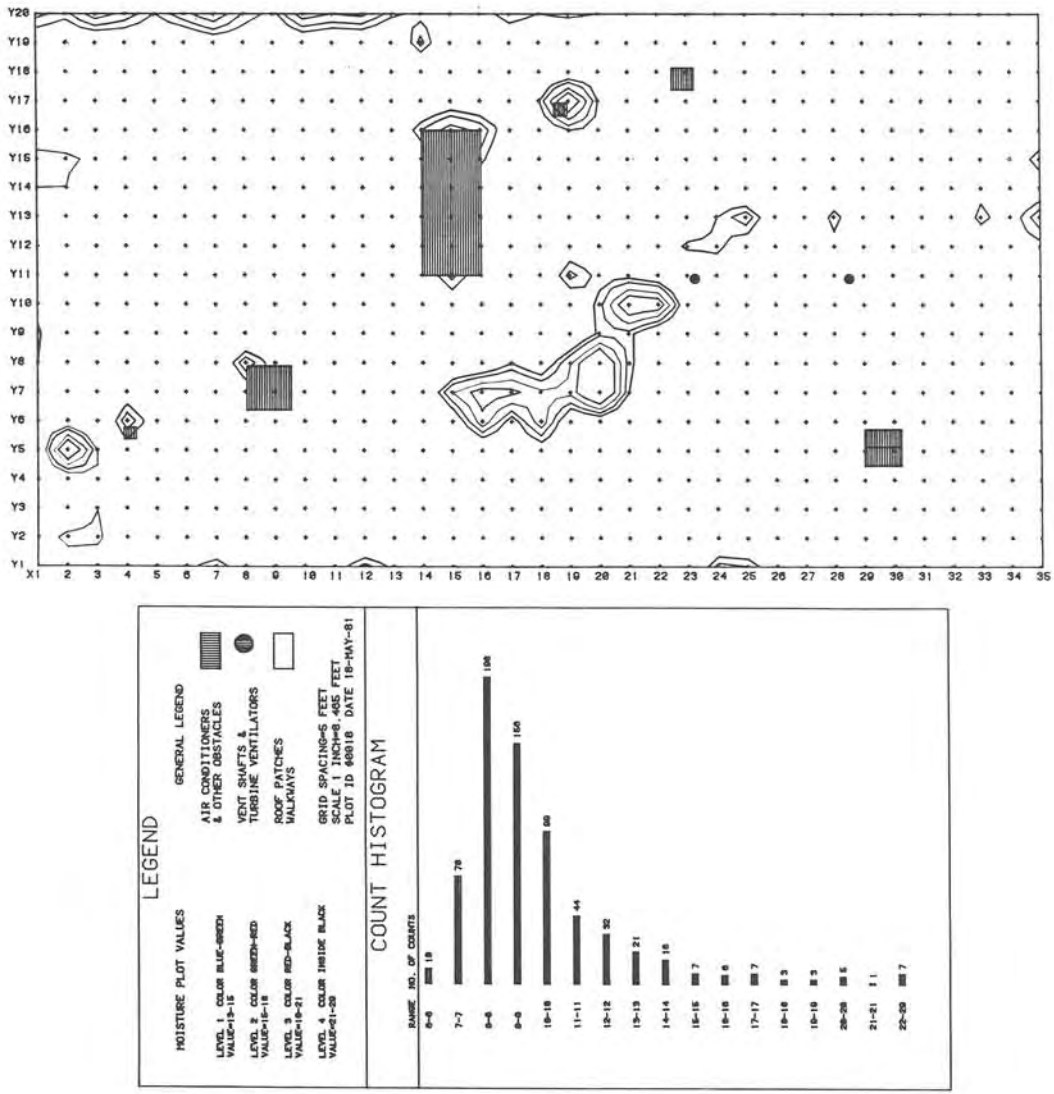
If the measurement counts taken during the data collection phase are recorded on a Roof Plan Grid, the data can be entered into a computer for processing. It is of utmost importance that the numbers be legible.

Below is a summary of the operations performed.


Operator Inputs
Computer Operation
Entry of setup conditions (plot name, grid size, max. X and Y, etc.).
Entry of roof measurement data.
Determination of histogram interval size.
Sorting of data into histogram intervals.
Drawing of histogram and legend chart.
Determination of plot intervals based on user submitted core sample data and/or histogram.
Reduction of measurement count data and generation of drawing file.
Plot of roof survey.
Entry of roof structures, north orientation, and roof outline.
Plot of roof structures, etc.
- - Optional - -
Drawing of roof plan with data counts reproduced at grid intersections or duplicate plots.

The user must realize that the determination of plot intervals is done by the computer operator, not by the computer. The variations produced by various type roofs, degrees of moisture penetration, previous repair work, unusual surface conditions, etc. dictate that additional information is needed before determination of plot intervals. Core samples are the best method for correlating absolute moisture levels and relative count rates.

Below is a sample of a computer aided plot.



Computer Aided Plot
Figure 3-9

III-D. VERTICAL WALL MEASUREMENTS

There are occasions when you may want to determine the relative moisture content of vertical surfaces. Examples include wall insulation, sheathing materials, etc. While the 3216 is not position sensitive and can be used in any orientation, it was designed for use on a horizontal surface.

Please note that the gauge base must be firmly held against the surface being tested. Any air gap or movement can affect the measurement.

IV. SENSITIVITY DATA

Many users notice that sequential measurement counts, taken on the same site, produce different count rates. This variation is expected since radioactive decay is a random phenomenon. One may also wonder how much effect this variation in count has on the final moisture content. The gauge precision is a measure of this variability.

The precision of the 3216 is stated on the data sheet for moisture content values of 0, 100, and 200 kg/m^3. The table below lists these same values for a larger number of moisture contents. There are times when this information is useful to the operator. The values may vary slightly from unit to unit.

MOISTURE CONTENT (kg/m^3)	PRECISION ($\pm kg/m^3$)		
	7.5 SEC	15 SEC	60 SEC
00	4.74	3.35	1.67
100	8.46	5.98	2.99
200	10.98	7.77	3.88
300	13.03	9.21	4.61
400	14.79	10.46	5.23
500	16.37	11.57	5.79
600	17.81	12.59	6.30
700	19.13	13.53	6.77
800	20.38	14.41	7.20
900	21.55	15.24	7.62
1000	22.66	16.02	8.01

The values stated are the "one sigma" deviations with a confidence limit of 68%. Doubling the values in the table above gives the "two sigma" deviations with a 95% confidence limit.

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V. PERIODIC MAINTENANCE

V-A. BATTERY CHARGING

Numerous factors (charge rate, discharge rate, temperature during charge/discharge, number of charge/discharge cycles, self-discharge, age of cells, etc.) affect the ability of nickel-cadmium batteries to accept a charge and then deliver this power to a load. Therefore, specifying operating time per battery recharge is difficult.

The 3216 instrument typically has a power consumption of less than 100 milliwatts. Since the battery stores approximately 14 watts, the 3216 will operate for 130 hours before requiring a full recharge. Assuming an 8 hour day, the 3216 should operate for approximately two weeks between recharging. If the battery has been used to the point where either the BAT alarm is displayed or the battery voltage is below the automatic shutdown, the recharge period using the AC charger will be 16 hours or overnight for a full charge.

The AC charger will operate from 115 or 230 volt power with the instrument at 50-60 Hz. While no damage will result to either the charger or the instrument connected to 115 volts and the charger switch set for 230, damage to the charger will occur if it is connected to a 230 volt supply with the switch set for 115 volt operation.

Using the above figures, one hour of recharge from the AC charger will replace approximately 8 hours of usage.

The DC charger cable will operate while plugged into a cigarette lighter receptacle of a 12 volt negative ground vehicle system. No damage will occur, but no charging will be possible in 6 volt or positive ground systems. The DC charger is intended for emergency use when required. With the vehicle engine in operation, use of the DC charger cable should be limited to a maximum of a two hour period. With the vehicle engine not in operation, use of the DC charger cable should be limited to a maximum of seven hours. Charging periods longer than those stated could damage the battery packs. A one hour charge will allow use of the gauge for about ten hours.

V-B. CLEANING

The surfaces of this instrument are corrosion resistant; however, the surfaces should be kept clean by wiping with a damp (not wet) cloth after use.

V-C. INTERIOR CONDENSATION

Under some climatic conditions, changes in atmospheric pressure will cause some flow of moist air in and out of the case since the instrument is not pressure sealed. This flow of air can result in the formation of water inside the case due to condensation. Condensation could cause erratic operation or even failure. This situation can be prevented by storing the gauge in a warm, dry area when it is not in use.

If condensation does occur, the instrument can be dried out by storage overnight in a warm, dry area with the cover removed.

V-D. GAUGE DISASSEMBLY

To disassemble the 3216 gauge, remove the six phillips head screws connecting the yellow top cover and the gauge base. Carefully lift the top cover up and lay it upside down beside the gauge base. You now have access to the gauge modules and battery packs.

CAUTION CAUTION CAUTION

This gauge generates HIGH VOLTAGE (1 kv) which can cause severe shock. Before removal or insertion of any modules, the unit must be turned off and the HIGH VOLTAGE DISCHARGE button pressed for 3-5 seconds.

Also, when measuring the HIGH VOLTAGE, be certain the measuring instrument and probes are rated for at least 1000 volts DC.

The HIGH VOLTAGE DISCHARGE switch is located on the baseboard printed circuit, between the two modules on the left side of the unit. See Figure VI-1 for the exact location of this switch.

To disconnect the top cover from the gauge base, unplug either end of the flat cable by grasping the connector firmly and pulling upward.

If you are going to perform a leak test (see section V-E), the entire electronic assembly can be removed by lifting upward on the electronic assembly mounting plate. Disconnecting the cables is unnecesary since they are long enough to allow the assembly to be placed on the right hand side of the base.

Perform the reverse process to reassemble the gauge.

V-E. LEAK TEST PROCEDURE

Leak testing is required as a condition of holding a Radioactive Materials License. The purpose of the test is to check for external removal contamination at the closest accessible point to the source.

To perform a Leak Test, using the Troxler Model 3880 Leak Test Kit:

1. Remove the paper filter from the envelope and write the gauge model and serial numbers on the filter . **Use a pencil** when writing this information on the filter paper; if a ball point, felt tip pen, or ink is used, it could be smeared when the radiac wash is applied (step 2), making the numbers unreadable.

2. Remove the tongs supplied with the kit and grasp the filter firmly, adding a few drops of the Radiac Wash to the filter. **Be careful not to oversaturate the filter.**

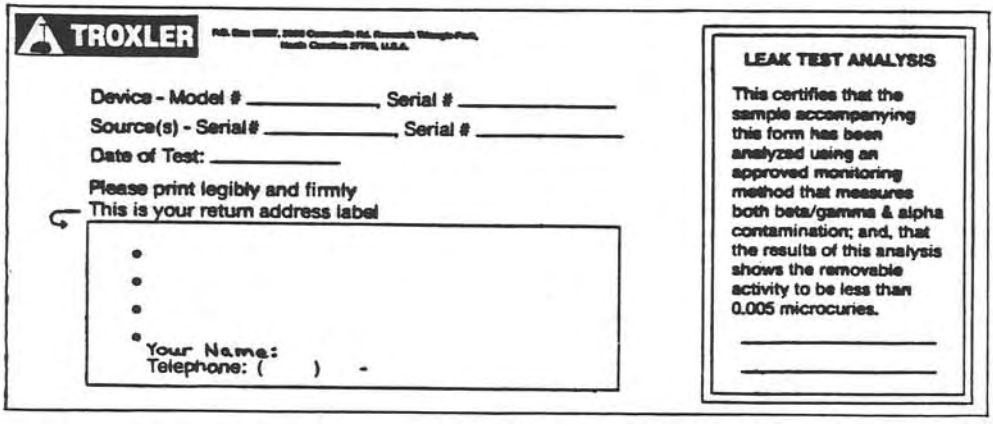
3. Remove the top cover and the electronic assembly as described in Section V-D. After the electronic assembly has been placed beside the gauge, the source holder can be seen, attached to the bottom of the gauge base. The top of the source holder is covered with a yellow "radioactive material" label. Using the wooden dowel supplied, wipe the appropriate location(s) (closest accessible point to the source) on the instrument with the side of the filter that the model and serial numbers have been written on. For exact locations of wipe point(s), refer to individual gauge manuals.

V-E. LEAK TEST PROCEDURE (cont'd)

4. Dry the filter wipe on a paper towel or use a low heat source before placing the wipe in the plastic bag provided. Do not fold the wipe.

5. Complete the leak test analysis form in the areas shown (Figure 5-1, below).

6. Remove and retain the middle copy of the analysis form for your records; send the rest of the copies and the plastic bag containing the filter wipe to Troxler Electronic Laboratories, Inc., Box 12057, Research Triangle Park, NC. 27709. Model 3880 refills are available.


TROXLER
Device - Model # _____, Serial # _____
Source(s) - Serial # _____, Serial # _____
Date of Test: _____
Please print legibly and firmly
This is your return address label
Your Name:
Telephone: ( ) -
LEAK TEST ANALYSIS
This certifies that the sample accompanying this form has been analyzed using an approved monitoring method that measures both beta/gamma & alpha contamination; and, that the results of this analysis shows the removable activity to be less than 0.005 microcuries.

Leak Test Analysis Form (Specimen)
Figure 5-1

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VI. SERVICE

The model 3216 utilizes a high degree of integrated circuit technology in custom modules. For this reason, the reliability level is very high, and repair is relatively simple since it consists of module replacement. 100% of the electronics may be replaced in the field without recalibration.

VI-A. EQUIPMENT REQUIRED

VI-A-1. HAND TOOLS

Screwdriver, 1/16" flat blade
Screwdriver, No. 2 phillips
Screwdriver, 1/16" allen hex
Nutdriver, 5/16"
Nutdriver, 3/8"

VI-A-2. INSTRUMENTS

While not required for service, the following instruments will make troubleshooting easier. The manufacturers' models listed are reasonable choices, but other manufacturers' equipment could be used equally well.

Digital Multimeter:
3 1/2 digit display, 0-20 volt DC ranges, 0-500 mA DC range
1) John Fluke model 8010A
2) John Fluke model 8022A
3) Hewlett-Packard model 3476A
4) Beckman model 3010

Oscilloscope:
10 MHz bandwidth, 10 mV to 10 V vertical deflection/division, 1µs/cm to 100 ms/cm sweep rate (triggered)
1) Tektronix model T922
2) Hewlett-Packard model 1222A

Power Supply:
0-20 VDC, 400 mA, constant-voltage/current limiting
1) Hewlett-Packard model 6215A
2) Tektronix model PS501-2 with TM501

High Voltage Meter:
800-1400 VDC range, 1% accuracy, input impedance $\geq$ 100 MΩ
1) Electrostatic Voltmeter
Sensitive Research Model ESD-7
Electrical Instrument Service, Inc.
25 Dock Street, Mt. Vernon, N.Y. 10550
Range = 600-1500 V AC/DC
Accuracy = 1% (0.5% optional)
Input Impedance $\geq 10^8$ MΩ
2) High Voltage Multimeter
Valhalla Scientific, Inc. Model 4500
Valhalla Scientific Inc.
7707 Convoy Court, San Diego, California 92111
Range = 200 mV to 15 kV (has 2kV range)
Accuracy = 0.5% at 1kV
Input Impedance = 100 MΩ on 2kV range

VI-B. GAUGE ELECTRONICS

A block diagram of the 3216 is shown in Figure 6-2. Figure 6-1 shows the modules and other major items. The gauge electronics consist of 1) a scaler printed circuit board attached to the inside of the top cover, 2) a baseboard printed circuit board, 3) He^3 detector tubes, and 4) battery packs. A remote START button and a piezoceramic beeper are located in the gauge handle.

CAUTION CAUTION CAUTION

This gauge generates HIGH VOLTAGE (1 kv) which can cause severe shock. Before removal or insertion of any modules, the unit must be turned off and the HIGH VOLTAGE DISCHARGE button pressed for 3-5 seconds.

Also when measuring the HIGH VOLTAGE, be certain the measuring instrument and probes are rated for at least 1000 volts DC.

Power for the gauge is supplied by two rechargeable, nickel-cadmium battery packs totaling 10 volts at 14 watt-hours. The two battery packs, separately replaceable, are connected to the baseboard where a circuit breaker provides excess current protection.

Power to the gauge is controlled by the Power Controller Module. The module contains a precision 5.0 volt regulator which powers the digital and linear circuits and also serves as a precision reference for the counting thresholds in the moisture amplifier modules.

The Power Controller contains voltage sensing circuits to activate the BAT alarm symbol when the battery voltage drops below 9.2 ±0.1 volts. Another voltage sensing circuit detects when the battery voltage drops below 8.4 ±0.1 volts and cuts off the gauge electronics. This circuit prevents deep discharge of the nickel-cadmium batteries. Both the alarm and cutoff circuits have at least 0.15 volts of hysteresis designed into the trip points.

The High Voltage Module is powered directly from the batteries and is turned on by the presence of the 5.0 volt supply. The module contains a very precisely regulated (±0.05%) voltage for all conditions of line, load, and temperature. The absolute voltage is 1000 ±20 volts. The high voltage is applied to the He^3 detector tubes via the Moisture Amplifier Module.

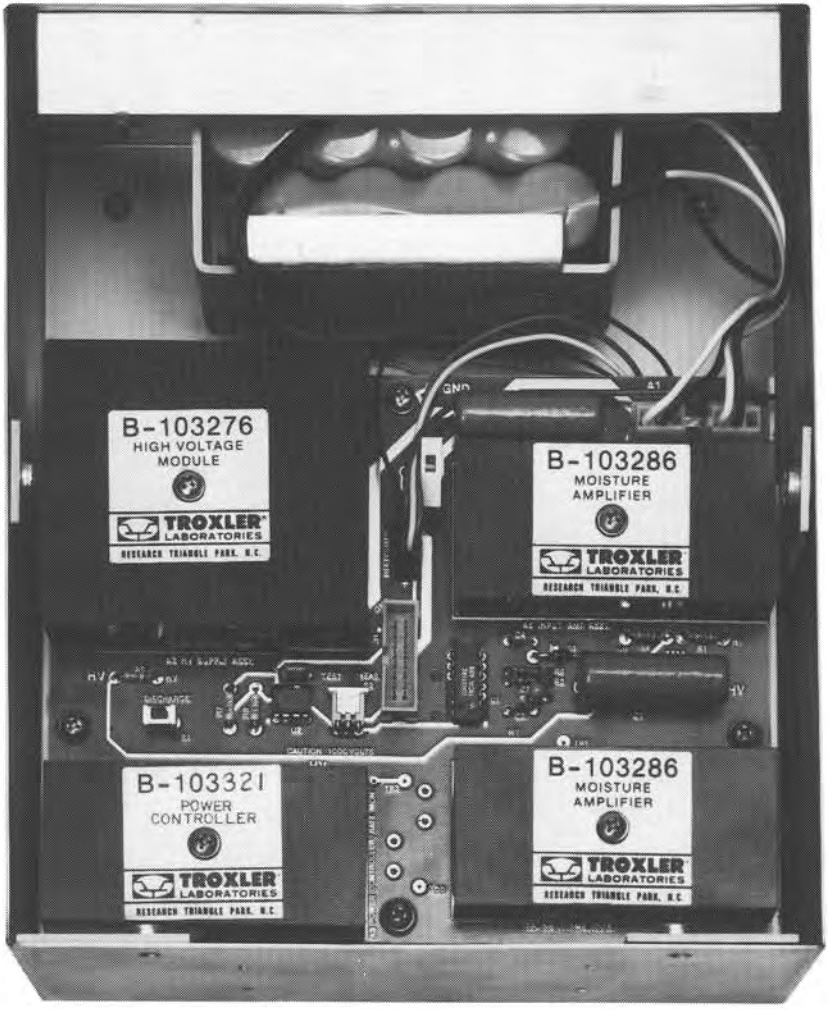
The Moisture Amplifier Modules contain the necessary circuitry to amplify and shape the pulses generated by the He^3 detector. The outputs of the amplifiers are then differentiated, by a resistor-capacitor combination and logically "OR'ed" together. This combined signal will be counted by the scaler circuits.

An astable multivibrator and a TEST-MEAS switch are also located on the baseboard. By sliding the switch to the TEST position, the signal from the multivibrator is substituted for the moisture amplifier pulses. Use of this circuit will allow the technician to isolate problems more quickly. The signal from the multivibrator should produce an accumulated count of 38 ±3.

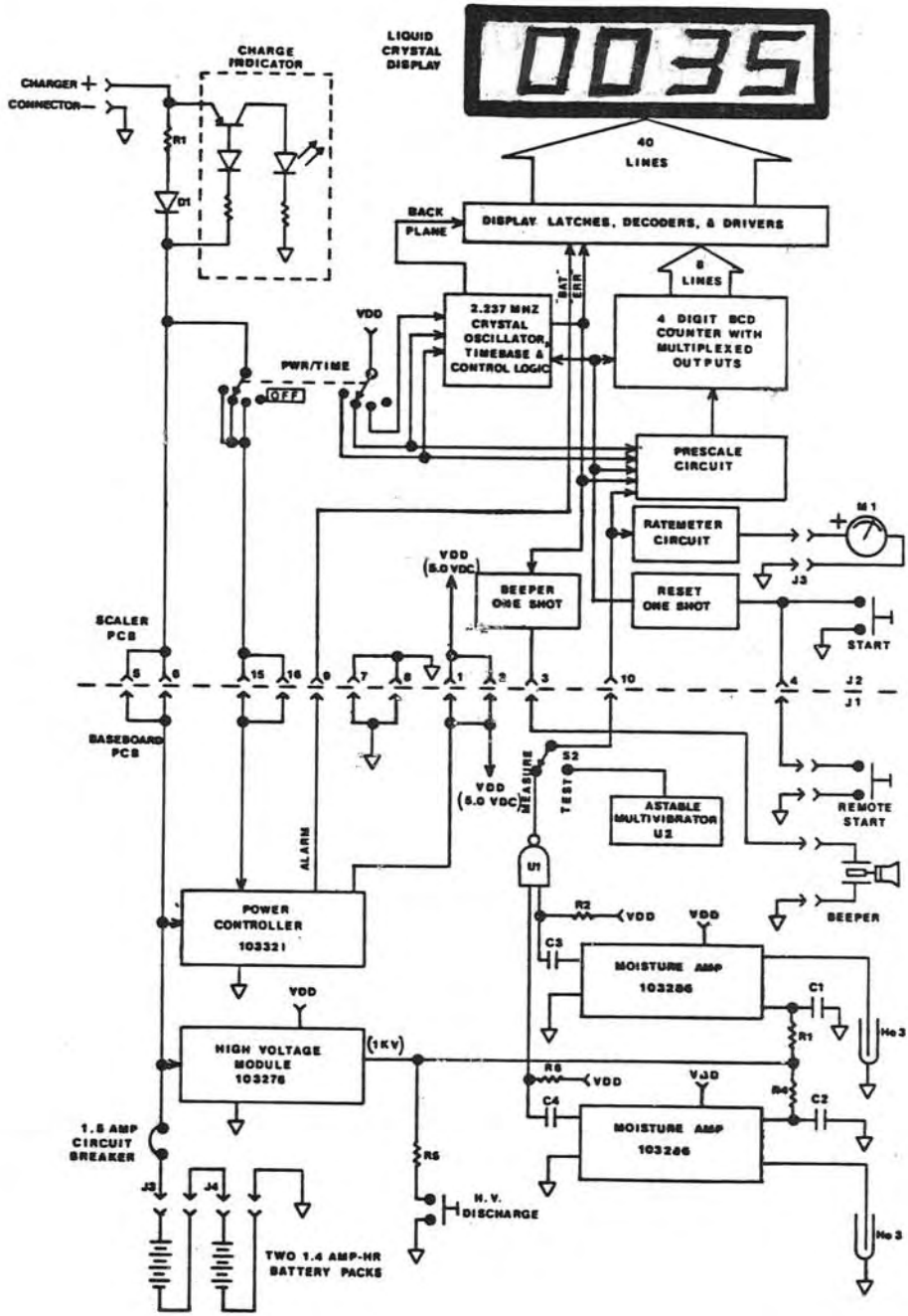
A sixteen lead flat cable connects the baseboard with the scaler board.

The scaler board contains a crystal oscillator, timebase and prescaler circuits, four decade accumulator, and display decoder and driver circuits. Due to the complexity of the integrated circuits used on the scaler board, a circuit description is not presented. If the scaler can accumulate the test signal described previously, then one can assume with a good degree of confidence that the scaler board is functioning correctly.

Also incorporated into the scaler board are the battery charger circuit and ratemeter circuit. The battery charger circuit provides for reverse polarity protection and has a charge indicator to inform the user when the charge circuit is functioning correctly. The ratemeter, though not calibrated, provides the user with a quick indication of the counting rate. There is a full scale adjustment for the meter on the back of the scaler board.



Interior Layout
Figure 6-1



Block Diagram of Gauge Electronics
Figure 6-2

VI-C. STATISTICAL STABLILITY

Radiation and the detection of radiation involve statistics in the form of the Poisson distribution. If count rate data fails to follow a normal distribution, this failure is an indication of false counting due to noise or instability in the detector and/or the high voltage power supply.

After the gauge has been on for 5 to 10 minutes, take a series of twenty counts in the 7.5 SEC mode. These counts should be taken on a surface that produces as high a count rate as possible. A concrete floor covered with asbestos tile will suffice.

Compute the average for the set of 20 counts and then take the square root of this average. The difference between the lowest and highest number in the set of 20 counts should not exceed the square root of the average. If the range of numbers does exceed the square root of the average, then a stability problem exists and the gauge must be serviced.

TEST NUMBER	MEASUREMENT COUNTS	
1	26	* High Count
2	25	
3	23	
4	24	
5	25	
6	24	
7	23	
8	26	
9	22	* Low Count
10	24	
11	24	
12	24	
13	25	
14	25	
15	25	
16	24	
17	23	
18	24	
19	24	
20	26	
	Σ = 486	

$$\text{Average} = \frac{486}{20} = 24.3$$

$$\sqrt{\text{Average}} = \sqrt{24.3} = 4.93$$

Statistical Test Data
Figure 6-3

VI-C. STATISTICAL STABLILITY (cont'd)

The statistical stability test given above is based on the fact that radioactive decay is described by the Poisson distribution. The most significant property of the distribution is that the standard deviation in the mean is given by the square root of the mean.

In Figure 6-3, the square root of the average is taken in performing the stability test. If the counts for the 3216 were not "prescaled", this number (4.93) would represent one standard deviation. Before the counts are displayed on the 3216, however, they are internally divided by the following prescale factors:

7.5 sec count	-	prescale = 16
15 sec count	-	prescale = 32
1 minute count	-	prescale = 128.

Therefore, in order to obtain the sample standard deviation(s) in the mean of a series of 7.5 sec counts, one would use the following formula:

$$s = \sqrt{\frac{\bar{X}}{16}}$$, where $\bar{X}$ is the mean.

One can see, then, that the value of 4.93 in the example is four times the value of s. For normally distributed data, 95.4% of the measurements should fall in a range of $\pm$ 2s about the mean. Hence, using the square root of the mean of the 7.5 sec counts in Figure 6-3 to establish an expected range for the twenty counts provides a simple means of testing the stability of the instrument.

Gauge Status	Possible Causes
1) Instrument fails to display when power is turned on.	Batteries are discharged below the cut-off voltage. Plugging in the charger should light the charge indicator lamp and power up the gauge.
2) Charge indicator lamp doesn't light when charger is plugged in.	Power may not be available at the receptacle into which the charger is plugged. Circuit breaker inside instrument has been tripped. Remove top cover (see Section V-D) and check breaker status. See Figure 6-1 for the location of the circuit breaker. If the breaker has been tripped, the indicator light will be gray. If the circuit is active, the indicator will be red. The 115/230 selector switch located on the charger may be in the 230 position when the available power source is 115.
3) Charge indicator lamp does light when charger is plugged in, but the instrument doesn't indicate an "on" condition.	Defective battery monitor module.
4) Gauge will operate only while charger is connected, but the charge indicator light doesn't light.	Circuit breaker inside instrument has been tripped (see above).
5) Instrument turns on but will not count when an accumulation is attempted.	If ERR indicator is displayed for the correct duration, remove top cover and try a TEST count (see Section VI-B). See Figure 6-1 for the location of the TEST/MEAS switch. If ERR indicator does not light, the scaler module is probably defective.
6) Instrument can accumulate a TEST count but will not accumulate moisture count.	Check the high voltage with an electrostatic voltmeter (see CAUTION note on page 6-2). If high voltage is not present, replace the high voltage module. If high voltage is present, replace moisture modules and/or He^3 detectors located in the gauge base.
7) Instrument counts moisture but is erratic and will not meet the stability test.	Systematically replace the HV module, moisture modules, and/or the He^3 tubes until the defective component is located. Run a stability test after each replacement.

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VII. PARTS LIST

VII-A. REPLACEMENT PARTS

103021	Liquid Crystal Display
103286	Moisture Preamplifier Module (2 req'd)
103300	Baseboard PCB Ass'y (without modules)
103321	Power Controller Module
103325	Scaler PCB Ass'y
103355	Battery Pack (2 req'd)
103356	Flat Cable Ass'y
103374	Ratemeter
104094.0001	Moisture Tube Assembly (2 req'd)
104639	High Voltage Module, 900 V
108709	High Voltage Module, 1000 V

VII-B. ACCESSORIES

021140	Radiation Sign Kit
102868	Leak Test Kit, Model 3880
102873	1oz Solution Detergent
102876.0005	Leak Test Replacement Packets (4 units)
102957	12 V DC Charger Cable
103367	Instruction Manual
104508	AC Battery Charger, 13.5 V, 140 mA (Dom. Sales)
104509	AC Battery Charger, 13.5 V, 140 mA (Int. Sales)
104621	3216 Case/Foam Ass'y
109661	Troxler Survey Meter

A "marking stick" is useful for spot marking the grid intersection points on the roof. This or similar holders for spray paint cans should be available from local surveyors and construction equipment dealers.

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VIII. THEORY OF MEASUREMENT

The 3216 measures the hydrogen content of a material on the basis of neutron thermalization. The following sections give an elementary discussion of the theory of measurement.

VIII-A. NEUTRON RADIATION AND MATTER

While the nucleus carries a positive charge, the neutron has no electric charge; therefore, a neutron must approach the nucleus much more closely than a charged particle to interact. The probability of interaction can be related to the ratio of the cross sectional area of the nucleus to the cross sectional area of the atom. Since this ratio is very small, the neutron has a path length much greater than other particles and is able to penetrate very large masses of high density material in contrast to other types of radiation.

Isotopic sources of neutrons are produced by (α,n) and (γ,n) reactions. The americium-241:beryllium source in this instrument is of the first type. The americium-241 is used as a source of alpha particles and beryllium as the target material. The reaction may be expressed as:

$$Be^{9}\ (\alpha,n)\ C^{12}\ ,$$

which states simply that the (α,n) reaction with beryllium-9 produces carbon-12. Neutrons produced by this reaction have a spectrum of energies ranging from 0 to approximately 10 MeV, the average neutron energy being about 4.5 MeV. The carbon-12 is left in an excited state and produces a 1-10 MeV photon going to the ground state.

Neutron interactions with matter are very complex, involving probability and diffusion theories for the calculation of neutron fluxes. For engineering measurement applications, the problems can be greatly simplified. The three primary interactions are: inelastic scattering, elastic scattering, and absorption.

Inelastic scattering, or collisions involving the transformation of kinetic energy to some other form of energy, is only important for fast or high energy neutrons (generally above 10 MeV). Since the average neutron energy produced by this instrument is 4.5 MeV, inelastic scattering need not be considered.

Elastic scattering involves the transfer of kinetic energy from the neutron to the nucleus, and is by far the dominant interaction when moderate (<10 MeV) neutron energies are involved.

The maximum amount of energy that can be transferred per collision is dependent only on the mass of the nucleus that is involved; the smaller the nucleus, the greater the energy that can be transferred. When a neutron collides with the normal hydrogen nucleus, all of the kinetic energy could be transferred to the hydrogen nucleus or proton. For any nucleus of mass number A, the maximum energy transfer can be calculated from:

$$E_1 - E_2 = \frac{4A}{(1 + A)^2} E_1$$

where: E_1 = Initial Energy
E_2 = Final Energy

The previous equation assumes a "dead center" collision. From a probability standpoint this seldom occurs; the collision is usually a glancing situation where only a portion of the maximum loss takes place. A more useful equation, which gives the number of collisions necessary to reduce a neutron from an initial energy E_1 to a final energy E_2, is:

$$N = \frac{\text{Ln } (E_1/E_2)}{1 + \frac{(A-1)^2}{2A} \text{ Ln } \frac{A-1}{A+1}}$$

As multiple collisions take place, the energy of the neutron is reduced to the point where it is in thermal equilibrium with a gas at 20°C (68°F). In this situation, the neutron may either gain or lose energy in a collision. In this condition, the neutron is called "thermal" and has an average energy of 0.025 MeV, which corresponds to a velocity of approximately 2200 meters per second.

Figure 8-1 lists the common earth crust elements and the average number of collisions required to produce the thermal condition.

The third interaction of neutrons with matter is neutron absorption. In this situation, the neutron enters the nucleus of an atom; the nucleus is raised to a high energy state and particles or photons are emitted from the nucleus.

As an example, boron-10 absorbs a neutron and becomes boron-11, which decays by emitting an alpha particle, becoming lithium-7. This reaction is an example of the (n,α) process. Another example is helium-3, which is transformed into hydrogen-3 by the (n,p) process. Both of these examples are good processes for the detection of thermal neutrons, since the probability of them occurring is quite high.

The probability of absorption is given in terms of barns which have units of 10^{-24} cm^2. The unit is related to the probability that a thermal neutron will be captured by a nucleus. A table of absorption cross sections for earth crust elements is given in Figure 8-1. These values are given for the average of naturally occurring isotopes for various elements, but some isotopes are vastly different from the average. For example, the boron absorption cross section is 759 barns, but is 3840 barns for the boron-10 isotope. The absorption cross section of natural helium is 0.007, but helium-3 is 5327.

The absorption cross section is a value established for thermal energies and decreases rapidly with an increase in neutron energy. For this reason, the absorption process is a good means of detection of thermal neutrons. The neutron, having no electric charge, cannot be detected directly, but the resulting & particles or protons from (n,α) or (n,p) reactions can be easily detected. Boron triflouride or helium-3 detectors are generally used for this purpose.

From Figure 8-1, one sees that if thermal neutrons are produced in normal soil, the probability is very good that they are produced by the interaction with hydrogen. The next element commonly found in soil, oxygen, requires over eight times the number of collisions to produce a thermal neutron.

Element	Weight Fractions of Earth's Crust	Average Collisions to Thermalize a 4.5 MeV Neutron	Thermal Absorption Cross Section
Hydrogen	0.0014	19.0	.33
Boron	*	109.2	759.00
Carbon	*	120.6	.0034
Nitrogen	*	139.5	1.90
Oxygen	0.466	158.5	.0002
Sodium	0.028	224.9	.53
Magnesium	0.021	237.4	.063
Aluminum	0.081	262.8	.23
Silicon	0.277	273.3	.16
Phosphorous	0.001	300.8	.19
Sulfur	*	311.1	.51
Chlorine	*	343.3	33.00
Potassium	0.026	378.0	2.10
Calcium	0.036	387.3	.43
Titanium	0.004	461.6	6.10
Manganese	0.001	528.5	13.30
Iron	0.050	537.2	2.53
Cadmium	*	1074.6	2390.00
Lead	*	1975.5	.17
Uranium	*	2268.6	4.20

* Note: Weight fraction is less than 0.1%.

Neutron Interaction Data
Figure 8-1

VIII-B. MOISTURE GEOMETRY

The moderation of fast neutrons to thermal energy levels and detection of the thermal neutrons can be a useful means of measurement of moisture content if certain assumptions can be made. The ideal situation would require that all thermal neutrons produced within the material be the result of interaction with hydrogen in the form of water. Since this situation does not exist, one must assume that other moderating elements and hydrogen not contained in water are reasonably constant. Fortunately this situation does exist in construction type materials. Oxygen, with a concentration of roughly 47 percent, is constant to within a few percent. The other moderators, such as deuterium (H-2), helium, lithium, beryllium, carbon, or nitrogen, are not present in sufficient quantities to create large errors. Agricultural soils may contain sufficient organic materials and nitrogen to cause errors.

One must also assume that no elements are contained in the material which would absorb thermal neutrons. This situation would also create errors since the absorbed neutrons would not reach the detectors. For construction type soils, only boron is likely to be encountered and could cause large errors. Coastal soils may also contain sufficient chlorine to be significant, and iron oxide deposits above 35-40 percent may cause errors.

Since the above elements may exist in sufficient quantities, a means must be provided to compensate for errors. These procedures were covered in Section III-B on field use of equipment. The use of He^3 detectors provides some improvement over BF-3 detectors since they are also sensitive to neutron energies higher than the thermal level.

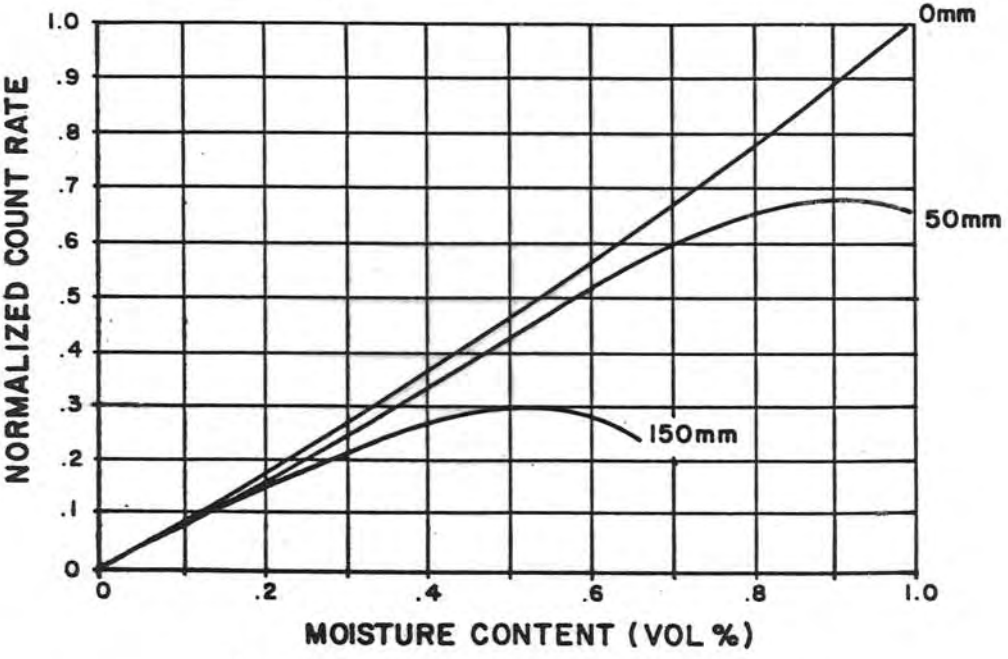
In choosing a geometry for the source and detector, one must consider the diffusion of thermal neutrons through the material. If small quantities of water are present, the neutrons become thermalized at a large distance from the source, and as the quantity of water per unit volume increases, the average neutron becomes thermalized closer to the source. The neutron flux density (neutrons per cubic centimeter) decreases as the square of the distance from the source; therefore, the location of the detector becomes critical.

In order to obtain maximum sensitivity (thermal neutrons detected per unit water density), the source and detector should occupy the same space. This geometery, however, produces a response which is very good (linear) at high water contents but poor at low moisture contents. This response occurs since the average neutron becomes thermalized at a large distance from the detector, which reduces its probability of being detected due to the diffusion of the thermal neutron. This response is shown in Figure 8-2.

At the other extreme, if the source and detector are separated by a large distance [100-150 mm (4-6 inches)], the linearity at low moisture contents is very good. At high moistures, however, the average neutron becomes thermalized at a point close to the source but at an increasing distance from the detector, and the response begins to flatten and ultimately decrease.

The instrument is more sensitive to a unit mass of water located close to the source-detector plane than an equivalent amount which is further from the center of measurement.

Since the detector response to a unit mass of water is dependent on the distance between them, the measurement is not a true average of the wet material under the gauge but is an average heavily weighted by the water closest to the gauge.



Effect of Neutron Source-Detector Distance Figure 8-2

VIII-B. MOISTURE GEOMETRY (cont'd)

Defining the depth of measurement for moisture is not simple since the moisture depth of measurement is a function of the moisture content and decreases with an increase in moisture. A set of normalized curves is shown in Figure 8-3, which illustrates the effects of moisture content on the depth of measurement.

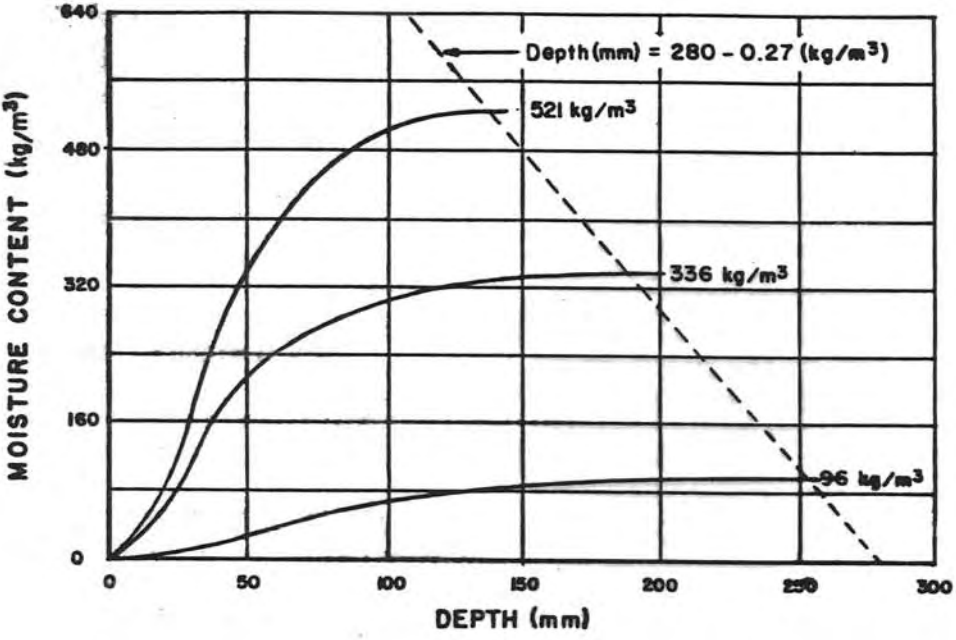
Using the data taken to arrive at the curves shown in Figure 8-3, we can express the relationship between the depth and the moisture content as:

$$\text{Depth (mm)} = 280 - 0.27\ M\ (kg/m^3)$$

or

$$\text{Depth (inches)} = 11 - 0.17\ M\ (PCF)$$

This equation covers 98% of the measured volume and is valid over the moisture content range of 0-640 kg/m^3 (0-40 PCF).



Effect of Moisture on Depth of Measurement
Figure 8-3

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IX. FACTORY CALIBRATION

IX-A. MOISTURE CALIBRATION

Many attempts have been made to create satisfactorily stable moisture standard either by using water and soil mixes or by simulating moisture by mixing hydrogen-bearing materials with other materials simulating soils. Some standards are totally inaccurate, and some are very unstable unless particular attention is paid to maintaining water levels and preventing evaporation.

During the development of moisture measurement gauges, Troxler Electronic Laboratories, Inc. developed a set of standards made from laminated sheets of plastic and a non-absorber of thermal neutrons. This process has been patented (.) During the process of manufacture the ratio of plastic (or other hydrogen-bearing material) and a non-absorber can be accurately controlled. To ensure uniformity, laminations were chosen rather than mixing of small particles. Such a mixing process tends to result in segregation due to the differences in the specific gravity of the materials. The materials used in the Troxler standards are non-hydroscopic and have zero voids, so changes in humidity do not affect the equivalent water content.

The count rate data accumulated during the calibration process are used to solve the equation:

$$\text{Count Rate} = m \times (\text{Moisture Content}) + b$$

Where m is the *slope* of the calibration curve and b is the *intercept* of the calibration curve. Once the values of m and b are evaluated, the terms of this equation are usually re-arranged so that the moisture content can be computed from the count rate. The resulting equation is:

$$\text{Moisture Content} = (1/m) \times (\text{Count Rate}) - (b/m)$$

The value (b/m) is often referred to as the *offset* value of the calibration equation.

IX-B. MOISTURE PERFORMANCE PARAMETERS

A computer-generated calibration report is supplied with the 3216 gauge. This 2-page report summarizes the calibration process and results. While the 3216 is intended for relative moisture measurements, it must be calibrated against known moisture standards to verify the gauge characteristics. An example of a typical Model 3216 calibration report is shown in Figure 9-1.

A summary of the contents of a Model 3216 calibration report is presented hereunder. The report consists of six separate parts, contained on two pages:

1. The first four lines of text at the top of the first and second pages of the report are the *header*. His portion of the calibration report contains data that identify the gauge itself (gauge serial number, model number, source serial number, gauge type) and the date when the calibration was done and the report was printed.

2. The second section of the calibration report is composed of two sentences that identify the units that are used with the different quantities listed in the calibration report and instruct the user on how to distinguish these units.

3. The section beginning with “Calibration Measurement Data” lists the data collected during the calibration of the gauge that are used to compute the slope and the intercept of the calibration curve itself. These data include the moisture values of the two calibration blocks and the counts that were acquired by the gauge on these blocks.

4. The section beginning with “Calibration Equation” explains the form and meaning of the calibration equation. This section also describes how the calibration equation is re-arranged in order to compute soil moisture values directly by using the gauge count.

5. The section beginning with “Precision for various measurement times” lists the *precision* values for the calibration equation. These precision values are presented in tabular form and are evaluated at three different moisture levels and three different counting times. The precision defines the repeatability of a measurement or the minimum change in moisture that is detectable by the gauge. The precision is the uncertainty (expressed as one standard deviation) in the measured moisture content based on the uncertainty (expressed as one standard deviation) of a given gauge count due to the decay rates of radioactive material. Figure 9-2, a plot of a calibration curve for a Model 3216 gauge, includes a graphic illustration of precision.

6. The second page of the calibration report begins with the header, followed by six paragraphs of *summary information*. This summary information is included to address specific requirements for calibration reports. The first paragraph of the summary information defines the ideal conditions of the measurement material for which ensure the optimal performance of the gauge. The second paragraph references the traceability of the moisture value of the mag/poly block used in the calibration. The third paragraph ensures the user that the gauge was operating properly during and after the calibration, instructs the user that the report is applicable only to the specific instrument described in the report, and informs the user of the identity of the technician who calibrated this instrument and when it was calibrated. Paragraph 4 gives the address of the facility where the gauge was calibrated, and paragraph five is the special considerations and limitations statement. Finally, paragraph six requests that the data in the report not be misrepresented by omitting or altering its contents, unless such a modification is formally approved by Troxler Electronic Labs.

Troxler Model 3216 Calibration Report - Page 1 of 2

Model: 3216A Serial: 00512 Calib. date: Mar 21, 2005
Source: AM-241/Be Serial: 78-976 Print date: Dec 07, 2005

Neutron Surface Moisture Gauge

******

The performance parameters, calibration constants, and moisture values for this instrument are listed both in SI units (kilograms per cubic meter) and in US Customary Units (pounds per cubic foot). In each instance where the SI and US Customary values differ, the SI will be listed first, followed by the US Customary Units in parentheses.

******

Calibration Measurement Data

Standard	Moisture Content kg/M3 (pcf)	Counts/Min.
Magnesium	0	9.0
Mag/Poly	606 (37.8)	108.4

******

Calibration Equation:

For the form of the linear equation y = mx + b, where x is the independent variable (moisture content), y is the dependent variable (gauge count), m is the slope of the calibration curve, and b is the intercept of the calibration curve, the calibration equation for this gauge is:

y = 0.1640x + 9.000, where x in in units of kilograms per cubic meter

or,

y = 2.626473x + 9.000, where x in in units of pounds per cubic feet.

For the form of the linear equation x = my + b, where x is the independent variable (moisture content), y is the dependent variable (gauge count), m is the slope of the calibration curve (also known as the Resolution), and b is the intercept of the calibration curve, the calibration equation for this gauge is:

x = 6.0987y - 54.888, where x in in units of kilograms per cubic meter

or,

x = 0.380739y - 3.427, where x in in units of pounds per cubic feet.

******

Precision for various measurement times

Moisture	<--------- Measurement Time --------->		
kg/m3 (pcf)	7.5 Sec.	15 Sec.	60 Sec
0 (0.0)	4.6 (0.29)	3.2 (0.20)	1.6 (0.10)
100 (6.2)	7.7 (0.48)	5.4 (0.34)	2.7 (0.17)
200 (12.5)	9.9 (0.62)	7.0 (0.44)	3.5 (0.22)

3216 Calibration Data (Sheet 1 of 2)
Figure 9-1

Troxler Model 3216 Calibration Report - Page 2 of 2

Model: 3216A	Serial: 00512	Calib. date:	Mar 21, 2005
Source: AM-241/Be	Serial: 78-976	Print date:	Dec 07, 2005

Neutron Surface Moisture Gauge

******

The calibration parameters for this instrument are based upon the measured material having a uniform moisture content equally distributed throughout the measured depths. The depth of measurement of this instrument will vary from 100 mm (4 inches) to upwards of 250 mm (10 inches) depending upon the moisture content of the material. These parameters may be significantly altered if the material thickness is reduced below the depth of measurement.

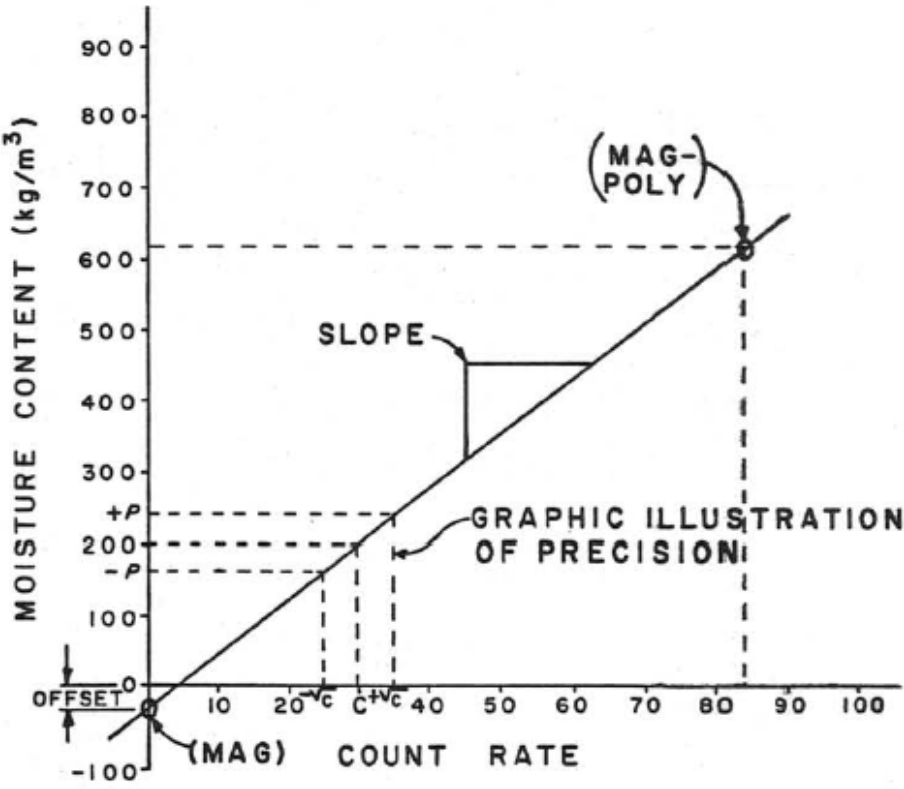
The above referenced equipment has been calibrated by the manufacturer to established and documented procedures. Moisture values for the standards used in the calibration of this equipment are based upon instrument response in siliceous soil. Test procedures and supporting documentation are available upon request

This instrument was found to be mechanically sound and electronically stable both prior to and after its calibration. All data listed in the preceding page of this report are applicable to this instrument only. This calibration was performed by JRS on 03-21-2005 at:

Troxler Electronic Laboratories, Inc.
3008 Cornwallis Road
Research Triangle Park, NC 27709
www.troxlerlabs.com

Special considerations and limitation of use for this device and its calibration are described in the Manual of Operation and Instruction provided with this instrument. This report shall not be reproduced, except in full, without the written approval of Troxler Electronic Laboratories, Inc.

3216 Calibration Data (Sheet 2 of 2)
Figure 9-1



Graphic Interpretation of Moisture Calibration
Figure 9-2

X. RADIATION THEORY AND SAFETY

The quantities of radioactive material contained in Troxler moisture gauges are quite small, and an operator may safely use a gauge daily without receiving any biological damage due to radiation. In addition, each radioactive source is doubly encapsulated to afford greater protection for the operator. However, all radioactive sources, no matter how small, should be handled with care.

The purpose of this section is to acquaint the operator with the types and characteristics of radiation with which he/she will be working and to describe methods to ensure safe operation of Troxler gauges.

X-A. RADIATION THEORY

A more detailed discussion of radiological theory can be found in the *Troxler Nuclear Gauge Safety Training Program* manual, provided at the Troxler radiation safety class.

X-A-1. ATOMIC STRUCTURE

All materials consist of chemical elements that can not decompose by ordinary chemical methods. Some examples are:

(H) Hydrogen	(C) Carbon	(O) Oxygen
(U) Uranium	(Cf) Californium	(Co) Cobalt

Each element contains an atom with a unique structure. The atom consists of smaller particles such as protons, neutrons and electrons. The protons and neutrons are grouped together in the nucleus (Figure 10-1). The electrons orbit the nucleus. An atom is normally electrically neutral because the positive protons cancel out the negative electrons.

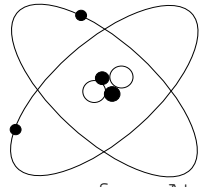


Diagram of an Atom
Figure 10-1

Protons carry a positive charge and are described as having a mass of one. Neutrons have a neutral charge and also have a mass of one. Electrons carry a negative charge and essentially have no mass.

	MASS (ATOMIC WEIGHT SCALE)	CHARGE
Protons	1.0073	+1
Neutrons	1.0087	0
Electrons	0.0006	-1

Since protons and neutrons are clustered together in the nucleus, the mass of an atom is concentrated in the nucleus. The atom in Figure 10-1 has two protons and two neutrons; therefore, it is a helium atom. The atomic weight of an atom is the sum of the protons and neutrons.

X-A-1. RADIATION THEORY

Radioactivity is the spontaneous breakdown of unstable nuclei (radioisotopes) with the resulting emission of radiation. The basic unit of radiation used in the U.S. is the curie (Ci). The Curie is defined as 3.7×10^{10} disintegrations of nuclei per second. In the "special form," encapsulated sealed source used in the 3216, the unit of measure is the millicurie (1/1,000 of a curie). The SI unit of radiation is the Becquerel (Bq). The Becquerel equals to one disintegration per second. Therefore, one curie equals 3.7×10^{10} Becquerels.

The strength of radioactive material is measured by its activity, or rate of decay. This activity decreases with time. The length of time it takes a given amount of radioactive material to decay to half of its original strength is referred to as the "half-life." The half-life of the 3216's source is approximately 432 years.

X-A-3. RADIATION TERMINOLOGY

The curie, defined as the quantity of radioactive material giving 3.7×10^{10} disintegrations per second, is equal to the number of disintegrations/second of one gram of radium-226. Note that the source used in the 3216 is small, with quantities expressed in millicurie (mCi).

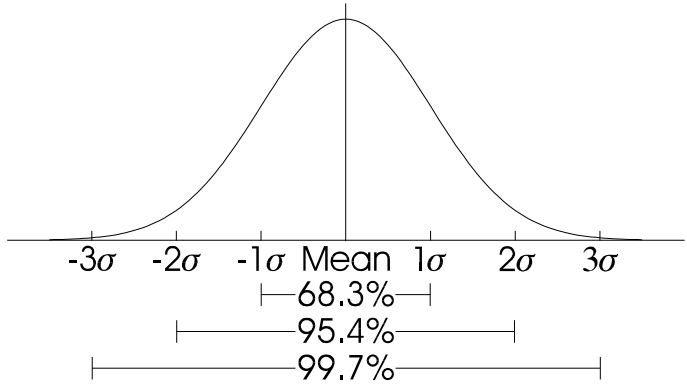
The **rad** or "**r**adiation **a**bsorbed **d**ose," is the unit of absorbed dose equal to 0.01 Joules/kg in any medium. To account for the effect of various types of radiation on biological tissue, the "**r**oentgen **e**quivalent **m**an" (**rem**) or more appropriate for Troxler users - the millirem - is used when measuring radiation dose. The unit rem is derived from scaling the radiation absorbed dose (rad) by a quality factor (QF). One rem is equal to the exposure of one **rad** of gamma radiation. For example, the average energy of an americium-241:beryllium neutron source is 4.5 MeV. The quality factor (QF) for this source is approximately 10. The absorbed dose of 1 rad of neutron radiation gives a dose equivalent of (absorbed dose x QF) 10 rem.

X-A-4. RADIATION STATISTICS

Radioactive emission is a random process. The number of emissions in a given time period is not constant but varies statistically about an average value. The variation about the true mean value is a Poisson distribution (Figure 10-2). In this distribution, the standard deviation (σ) about the mean (n) is defined as:

$$\sigma = \sqrt{n}$$

When the mean is greater than 100, the Poisson distribution can be closely approximated by the normal distribution (Figure 10-2). The normal distribution predicts the probability that any given count rate will fall within a selected region about the mean.



Normal Distribution

Figure 10-2
Variation of Radioactive Emission

Using the mean of a larger number of counts to approximate the true mean, the distribution shows that 68.3% of the time the count rate obtained will be within ±1 standard deviation of the mean. The figure above shows the probabilities for three different standard deviations of the mean. A statistical stability test may be performed to compare the experimental standard deviation to the theoretical standard deviation (see AII).

X-B. RADIATION SAFETY

This section provides a brief discussion of general radiation safety. The exposure profile for the Model 3216 gauge is also included, along with a discussion of the source encapsulation.

X-B-1. TYPES OF RADIATION

The radioactive source in the Model 3216 produces three types of radiation:

Alpha Particles
Gamma Rays (Photons)
Neutrons

The alpha particles are stopped by the source capsule. Only the gamma and neutron radiation can contribute to any occupational radiation exposure.

Gamma radiation is electromagnetic radiation, as are x-rays, radio waves, and visible light. Visible light and gamma rays have no mass, a zero electrical charge and travel at the speed of light. Gamma rays are energetic and penetrating. Dense materials (i.e., lead, cadmium, etc.) provide the best shielding against gamma radiation.

Neutron radiation allows measurement of the hydrogen (moisture) content in a material because the neutrons are slowed by collisions with materials containing hydrogen atoms (i.e. water, polyethylene, etc.). Neutrons have a neutral charge and are very penetrating.

X-B-2. LIMITING EXPOSURE

Under normal conditions a full time operator of the 3216 will receive less than 150 millirem per year.

Taking advantage of all available means to limit radiation exposure is always recommended. The three methods of limiting exposure are:

TIME
DISTANCE
SHIELDING

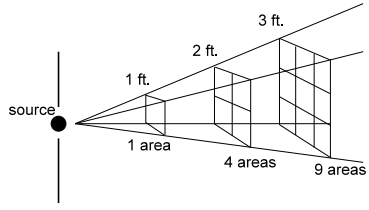
These methods are a part of an **"ALARA"** (**A**s **L**ow **A**s **R**easonably **A**chievable) program.

TIME

The simplest way to reduce exposure is to keep the time spent around a radioactive source to a minimum. If time is cut in half, so is the exposure, with all other factors remaining constant.

DISTANCE

Distance is another effective means to reduce radiation exposure. A formula known as the "inverse square law" relates the radiation exposure rate to distance (Figure 10-3). Doubling the distance from a radiation source reduces the exposure to one-fourth its original value. If the distance is tripled, the exposure is reduced by a factor of nine, etc.



Effect of Distance on Exposure
Figure 10-3

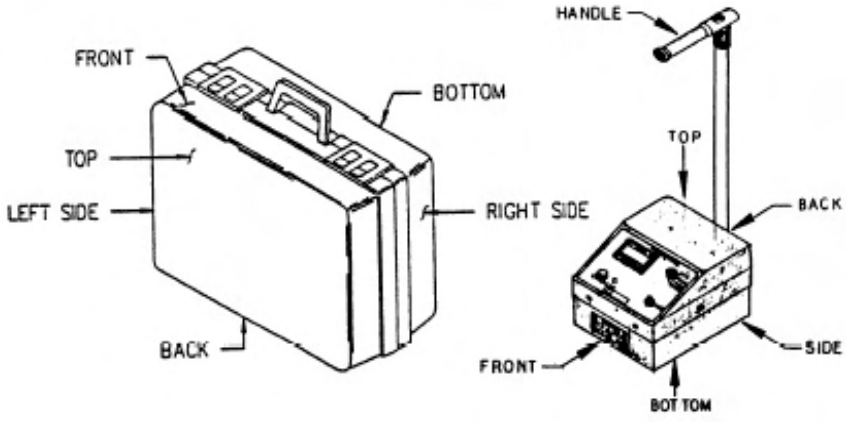
SHIELDING

Shielding is any material used to reduce the radiation reaching the user from a radioactive source. While some types of radiation such as alpha particles may be stopped by a single sheet of paper, other particles such as gamma rays and neutrons require much more shielding. Dense materials, such as lead, shield gamma rays. Materials containing large amounts of hydrogen, such as polyethylene, shield neutrons. The Model 3216 has shielding built into the system which reduces the exposure.

X-B-3. MONITORING RADIATION

Government agencies set occupational exposure limits. The current limit in the United States and many other countries is 5,000 millirem per year. Under average conditions a full time employee working with the 3216 will receive less than 150 millirem per year.

Anyone working with or near radioactive materials is subject to the limits of occupational exposure and must complete a radiation safety training course to be designated an authorized user. As an authorized user, an individual so designated must work in a "controlled" environment to the extent that their exposure to radiation must be monitored. Several means of personnel monitoring or *dosimetry* exist; the most common methods are film badges and TLD badges.



RADIATION PROFILE FOR 3216/3218 GAUGE

LOCATION	SURFACE			10 cm			30 cm			1 m		
	Gamma	Neutron	Total	Gamma	Neutron	Total	Gamma	Neutron	Total	Gamma	Neutron	Total
FRONT	0.20	3.0	3.2	*	0.8	0.8	*	0.3	0.3	*	*	*
BACK	*	0.4	0.4	*	0.2	0.2	*	0.1	0.1	*	*	*
SIDES	0.15	1.4	1.55	*	0.5	0.5	*	0.3	0.3	*	*	*
TOP	*	1.5	1.5	*	0.6	0.6	*	0.3	0.3	*	*	*
BOTTOM	1.00	4.5	5.5	*	2.5	2.5	*	0.5	0.5	*	0.1	0.1
HANDLE	*	0.3	0.3	*	0.15	0.15	*	*	*	*	*	*

RADIATION PROFILE FOR 3216 GAUGE IN PLASTIC CASE

LOCATION	SURFACE			10 cm			30 cm			1 m		
	Gamma	Neutron	Total	Gamma	Neutron	Total	Gamma	Neutron	Total	Gamma	Neutron	Total
LEFT	0.4	1.3	1.7				*	0.4	0.4	*	0.1	0.1
BACK	*	0.2	0.2				*	*	*	*	*	*
RIGHT	*	0.2	0.2				*	*	*	*	*	*
FRONT	*	0.7	0.7				*	0.2	0.2	*	*	*
BOTTOM	*	0.4	0.4				*	0.2	0.2	*	*	*
TOP	*	0.3	0.3				*	*	*	*	*	*

NOTE: RADIATION DOSE RATES IN MILLIREMS PER HOUR

1. *Dose rates measured by the State of North Carolina Department of Environment, Health and Natural Resources, Division of Radiation Protection.*
2. *Gamma Measurements in case made using Ludlum 14C Survey Meter, Calibrated March 1990.*
3. *Neutron Measurements in case made with Nuclear Research Corp. Model NP-2 Survey Meter, Calibrated March 1990.*
4. *Gamma Measurements of gauge alone made with a Victoreen Model 2035 Survey Meter.*
5 *Neutron Measurements of gauge alone made with a Nuclear Research Corporation Model NP-2 Survey Meter (detector physical location is 11.5 mm inside thermalizing housing).*
6. *Dose rates for 40 mCi Am-241:Be source.*
7. ** indicates a reading of less than 0.1 millirem/hour.*

Figure 10-4

X-B-5. SOURCE ENCAPSULATION

The source in the Model 3216 meets regulatory requirements of U.S. and international authorities as "SPECIAL FORM," or encapsulated, sealed source material. The "sealed" source used is encapsulated to prevent leakage of the radioactive material and meet radiation safety requirements.

Proper use of this instrument (following the instructions in this manual) and the shielding design of the instrument will keep the exposure levels at a minimum under normal conditions. It is, however, required that personnel dosimetry be used when using the 3216.

X-B-6. EMERGENCY PROCEDURES

If the nuclear gauge is lost or stolen, then immediately notify the Radiation Safety Officer (RSO).

The gauge owner should complete the emergency contact information on the lines furnished below.

The company RSO is _____.
Call the RSO at _____.

The regulatory agency is _____.
Call the agency at _____.

If a gauge is damaged, then follow the steps below:

- ✓ Locate the gauge and/or source.
- ✓ Do not touch or move the gauge.
- ✓ Immediately cordon off an area around the nuclear gauge and/or source. A radius of fifteen feet (5 m) will be sufficient. Do not leave the area unattended.
- ✓ Keep all unauthorized personnel from the nuclear gauge.
- ✓ If a vehicle is involved, it must be stopped until the extent of contamination, if any, can be established.
- ✓ The gauge user should perform a visual inspection of the nuclear gauge to determine if the source housing and/or shielding has been damaged.
- ✓ Use a survey meter to measure the dose rate at a distance of three feet (1 m) from the gauge.

✓ Contact the company RSO (name and number given at the beginning of this section). Provide the RSO with the following:

- ♦ the date, time, and location of the accident,
- ♦ the gauge model and serial number,
- ♦ the nature of the accident,
- ♦ the location and condition of the gauge and/or source,
- ♦ the dose rate at three feet (1 m) from the gauge.

✓ If you are unable to reach the RSO, then call your regulatory agency (name and number given at the beginning of this section).

✓ Follow the instructions of the RSO. The RSO should report the incident to the regulatory agency. The RSO may also be required to notify the USDOT of accidents during transport.

✓ Before shipping a damaged gauge to Troxler, obtain a RGA (returned goods authorization) number from the Troxler RSO.

XI. TRANSPORTATION AND SHIPPING

Devices containing radioactive materials must be transported in accordance with the rules of the U.S. Department of Transportation (DOT) and the International Atomic Energy Agency (IAEA). The IAEA recommendations have been codified in the International Air Transport Association (IATA) Dangerous Goods Regulations. International customers should consult their local government or licensing authority for applicable regulations.

XI-A. U.S. SHIPPING REQUIREMENTS

The U.S. DOT hazmat regulations (49 CFR, Parts 100-185) apply any time a nuclear device is transported by motor vehicle on a public highway or by other means of transport (rail, air, ship).

The major requirements for transporting a nuclear gauge in the United States are listed below. For more detailed information about these requirements, please refer to the *Troxler Transportation Guide*.

- A copy of the current IAEA Certificate of Competent Authority for each source in the gauge (Special Form Certificate) must be kept on file. Current versions can be downloaded from the Troxler website, www.troxlerlabs.com.
- A copy of the results of the Type A package testing must be kept on file.
- Hazmat employee training records must be kept on file.
- An *Emergency Response Information* document must be in the vehicle and immediately accessible to the driver.
- A properly completed bill of lading must be in the vehicle and immediately accessible to the driver. The shipping papers must include a 24-hr emergency response phone number.
- If shipping by air, a *Shipper's Declaration for Dangerous Goods* must accompany the air waybill.
- The package must be properly marked and labeled in accordance with hazmat regulations.
- The package must have a tamper-evident seal.
- The package must be inspected prior to each shipment.
- The package must be securely blocked and braced in the vehicle to prevent shifting during transport.

XI-A-1. ACCIDENT NOTIFICATION REQUIREMENTS

In the event of a reportable incident involving radioactive material, notify the licensing agency as soon as practical. The operator is also required to notify, at the earliest practical moment, the U.S. DOT at 1-800-424-8802 of an accident that occurs during the course of transportation (including loading, unloading, and temporary storage) in which fire, breakage, spillage, or suspected contamination occurs involving shipment of radioactive materials.

XI-A-2. HAZMAT TRAINING

The U.S. DOT regulations require every hazmat employer to train, test, certify, and maintain records for each hazmat employee. Hazmat training applies to anyone who transports or prepares for transport radioactive materials. Refresher training is required every three years.

XI-B. CANADIAN SHIPPING REQUIREMENTS

The Transportation of Dangerous Goods Act and Regulations (TDG) and Transport Packaging of Radioactive Materials Regulations (TPRM) apply any time a nuclear device used in commerce is transported by any means in Canada.

For training and accident notification requirements, consult the Transportation Of Dangerous Goods Regulations. For further information on transporting a nuclear device, contact the transportation section of The Canadian Nuclear Safety Commission (CNSC).

APPENDIX

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LIST


10 REM DEVIATION OF GROUP DATA FROM FREQUENCY HISTOGRAM
20 PRINT "DEVIATION OF GROUP DATA"
30 PRINT "ENTER NUMBER OF INTERVALS FOR WHICH DATA IS AVAILABLE"
40 INPUT M
50 S=0 \ T=0 \ N=0
60 PRINT "ENTER DATA FROM FREQUENCY HISTOGRAM"
70 PRINT "INPUT X(I),F(I) FOR I=1,2,...M"
80 PRINT "WHERE X(I) IS THE MIDPOINT OF EACH INTERVAL,"
90 PRINT "AND F(I) IS THE FREQUENCY OF OCCURANCE FOR THAT INTERVAL"
100 PRINT  \ PRINT
110 PRINT USING "              X=      F=        X*F=        X*X*F="
120 FOR I=1 TO M
130 INPUT X,F
140 S=S+F*X \ N=N+F \ T=T+F*X*X
150 PRINT USING "           ###.#    ####    ######.#    ########.#",X,F,X*F,X*X*F
160 NEXT I
170 M=S/N
180 D=SQR((T-(S*S)/N)/(N-1))
190 S1=M-3*D \ S2=M+3*D
200 PRINT USING "                      ____    ________    __________"
210 PRINT USING " SUMMATIONS >>      ####    ######.#    ########.#",N,S,T
220 PRINT  \ PRINT
230 PRINT USING "      MEAN=####.##",M
240 PRINT USING "STD. DEV.=####.##",D
250 PRINT
260 PRINT USING " THE THREE SIGMA LIMITS ARE  ####.#  AND  ####.# ",S1,S2
270 END

READY
```

BASIC Listing for Standard Deviation

```
RUN


DEVIATION OF GROUP DATA
ENTER NUMBER OF INTERVALS FOR WHICH DATA IS AVAILABLE
? 11
ENTER DATA FROM FREQUENCY HISTOGRAM
INPUT X(I),F(I) FOR I=1,2,...M
WHERE X(I) IS THE MIDPOINT OF EACH INTERVAL,
AND F(I) IS THE FREQUENCY OF OCCURANCE FOR THAT INTERVAL

                X=       F=        X*F=         X*X*F=
? 130,1
             130.0        1       130.0        16900.0
? 135,2
             135.0        2       270.0        36450.0
? 140,4
             140.0        4       560.0        78400.0
? 145,5
             145.0        5       725.0       105125.0
? 150,6
             150.0        6       900.0       135000.0
? 155,9
             155.0        9      1395.0       216225.0
? 160,10
             160.0       10      1600.0       256000.0
? 165,6
             165.0        6       990.0       163350.0
? 170,3
             170.0        3       510.0        86700.0
? 175,2
             175.0        2       350.0        61250.0
? 180,1
             180.0        1       180.0        32400.0
                        ----    --------    ----------
 SUMMATIONS >>            49      7610.0      1187800.0


     MEAN= 155.31
STD. DEV.=  11.11

 THE THREE SIGMA LIMITS ARE   122.0  AND   188.6

READY
```

Sample Output from Standard Deviation Program

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